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MISSION ROLES FOR THE SOLAR ELECTRIC PROPULSION STAGE (SEPS) WITH THE SPACE TRANSPORTATION SYSTEM

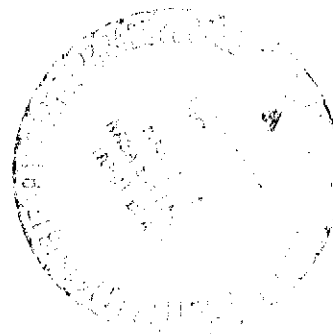
VOLUME I - EXECUTIVE SUMMARY

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PREPARED FOR:

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Program Development Directorate**

Under Contract NAS8-30742



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REVIEWED AND APPROVED BY:

A handwritten signature in black ink, appearing to read "D M Hammock". The signature is written in a cursive, flowing style.

David M. Hammock
Program Manager

FOREWORD

This volume, Volume I, presents an executive summary of the study "Mission Roles for the Solar Electric Propulsion Stage (SEPS) with the Space Transportation System." The summary covers the study objectives, relation to other NASA efforts, the principal results of the study, and suggested additional efforts. In this summary, emphasis is placed on the rationale leading to the concepts for the development and operations program which enhances the cost effectiveness of SEPS operating with STS. The approach in describing design concepts and configurations has been to emphasize the decision controlling factors and selection criteria rather than description of design detail.

Mr. Robert Austin of the Marshall Space Flight Center was the Contracting Officer's Representative for NASA. Mr. David M. Hammock was Northrop Services, Inc.'s, Study Manager.

The study was conducted under Contract NAS8-30742. Funding was \$130,000.

An understanding of the basic physics of the solar electric propulsion thrusters and the basic physical and performance differences between solar electric and chemical propulsion stages is essential to a proper assessment of the results and recommendations of this study. A section of this volume is therefore devoted to a brief, illustrative discussion of those factors.

The complete final study report is composed of 4 volumes:

Volume I	Executive Summary
Volume II	System Analysis and Evolution of Design and Operational Concepts
Volume III	Design Reference Mission Description and Program Support Requirements
Volume IV	Traffic Model and Flight Schedule Analysis Techniques and Computer Programs.

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Section I

INTRODUCTION

1.1 GENERAL

The Solar Electric Propulsion Stage (SEPS) is a space propulsion stage achieving high specific impulse (Isp) by the conversion of solar energy to electrical energy which is used in an electrostatic particle accelerator to produce a high velocity ion beam. A parallel beam of electrons is produced so that diffusion of electrons into the ion beam converts it into a neutral plasma jet obviating any space charge problems on the spacecraft or return flow of positive ions to the spacecraft. A specific impulse of more than 30,000 seconds is feasible with this general type of space propulsion system. The Isp range that is desirable for missions presently contemplated for the period 1979 to 1991 appears to be 2,500 seconds to 5,000 seconds. Technology programs from 1967 to the present time have demonstrated long life and continuous operation, in this Isp range, of flight suitable thrusters in laboratory tests and in research vehicle flight tests.

Previous SEPS mission and system definition studies have concentrated primarily on planetary exploration. As the Space Transportation System (STS) and its mission employment was defined in greater detail, it became obvious that a SEPS type vehicle with its high Isp, relatively unlimited stay time in space, small propellant weight requirement, and operational flexibility would greatly augment the Shuttle, IUS (Interim Upper Stage), and Tug capabilities in the areas of high energy transport, orbital taxi functions, and servicing functions.

The National Aeronautics and Space Administration (NASA), entering in 1974 that phase of SEPS concept definition where significant funding would be committed to design definition and Supporting Research and Technology (SRT) projects oriented to specific SEPS configuration concepts, considered it an appropriate time to:

- Critically review design defining trade studies and "optimization" results of past studies

- Ensure that system requirements and "baseline" system configuration characteristics derived from past studies were valid
- Ensure credibility of the cost effectiveness of SEPS as an added element of STS.

Therefore, NASA, through its George C. Marshall Space Flight Center, implemented the "Mission Roles for SEPS with the Space Transportation System" study to quantify SEPS potential capabilities and transportation cost savings.

1.2 STUDY OBJECTIVES

The primary objectives of the SEPS study were to:

- Define mission roles that are major contributors to transportation cost reduction when SEPS is operated as an element of the Space Transportation System
- Generate concepts for and perform operations analyses on:
 - * Payload exchanges with Shuttle, IUS, and Tug
 - * Multiple payload deployment and retrieval
 - * Payload maintenance and servicing in space
- Develop conceptual designs of payload handling and servicing equipment
- Identify SEPS interfaces with Shuttle, IUS, Tug, ground flight control centers, and launch support systems
- Define requirements not identified in prior studies and assess resultant design impacts on subsystems proposed in earlier studies.

Contributing secondary objectives of the SEPS study were to:

- Quantify transport cost effectiveness of SEPS with STS relative to a NASA supplied mission model
- Define a system operational profile with individual payloads assigned to specific flights which were to occur on specific dates
- Identify operational requirements and define SEPS program support
- Establish SEPS transport performance and show potential for improvement
- Identify benefits to IUS, Tug, and payload operations resulting from SEPS use
- Estimate operational costs of SEPS
- Identify problem areas for future investigation.

1.3 RELATIONS TO OTHER NASA EFFORTS

The reference mission model for quantifying the transportation cost savings and the definition of the "baseline" STS without SEPS were generated by the Marshall Space Flight Center. The "baseline" SEPS configuration ground rule for this study was the culmination of 3 years of NASA sponsored studies by Rockwell International Space Division, as generally defined in the final reports of their two latest studies*.

The performance of the power conversion units and thruster elements were based upon values from the Lewis Research Center's thruster subsystem control documents provided by MSFC in June 1974. Mr. Charles H. Guttman, MSFC, was the Contracting Officer's Representative for the Rockwell International Space Division studies.

Concurrent NASA in-house technology programs and other NASA sponsored studies contributing to the data base for this study were:

- Lewis Research Center's ongoing technology programs in solar electric propulsion power processors and thrusters
- Jet Propulsion Laboratory's thruster subsystem integration programs
- MSFC's ongoing programs in solar arrays and navigation and guidance analysis
- MSFC's Baseline Space Tug System Definition
- Hughes Research Labs and TRW's engineering model development and improvement programs for thrusters and power processors under Lewis Research Center sponsorship
- McDonnell Douglas' "Payload Utilization of Tug" and Follow-On (NAS9-29743 MSFC) and "IUS/Tug Payload Requirements Compatibility Study" (NAS9-31013 MSFC)
- International Business Machine's IUS/Tug Orbital Operations and Mission Support Study
- NASA supplied STS (other than SEPS) operational cost data.

* (1) *Feasibility Study of A Solar Electric Propulsion Stage for Geosynchronous Equatorial Missions*, DRL No. MA04 DPD304, Contract NAS8-27360, dated February 1973.

(2) *Extended Definition Feasibility Study for a SEPS Concept Definition*, DR No. MA04 DPD369, dated December 21, 1973.

1.4 STUDY APPROACH

The study effort was divided into five principal tasks. The systematic output of the tasks at a given level of detail allowed selection of competing concepts with a minimum of effort defining details of concepts later to be rejected. Successive iterations of the study were used to improve the concept of the selected system approach and to improve the accuracy of quantitative values used to support certain decisions.

The five study tasks were:

1. Mission Roles Identification and Analysis/STS Baseline Configuration Selection
2. Mission Operations and Systems Requirements Analysis
3. System and Subsystem Design Impacts Analysis
4. Interface Analysis
5. Cost Analysis.

The first step in establishing the transportation cost effectiveness of SEPS was to establish the maximum credible performance (minimum number of Shuttle flights) of STS without SEPS as the reference base for cost comparisons. To do this, NSI evaluated transportation capabilities of the NASA defined baseline STS in operational modes that would maximize its transportation efficiency. NSI assumed modified forms of operational modes and equipment concepts evolved for STS with SEPS that, if applied to baseline STS, would justify removal of arbitrary restrictions on the number of payloads that could be carried on any flight.

The sensitivity of cost savings to various operational constraints (such as multiple payload packaging restraints and arbitrary restrictions of numbers of payloads on a given flight that had been used in other studies) were determined. Transportation cost savings resulting from more compact Tug designs, higher Isp in SEPS, and higher SEPS power were investigated.

A concerted attempt to compare maximum capability STS operation to maximum capability STS with SEPS was made so that the transportation cost savings

attributed to SEPS would be conservatively based and as realistic as the reference mission model.

In Task II, design reference mission descriptions were generated to establish design requirements for flight articles and to define ground support requirements for the flight operations. Operational modes, organizations, and facility concepts that would minimize the cost for total SEPS Program Support were generated and defined.

In Tasks III and IV, new approaches (and new applications of older ones) were conceived for SEPS payload transport, handling, and servicing functions. New approaches were conceived for General Purpose Mission Equipment (GPME) for Tug and IUS that simplified IUS/Tug operations. Conceptual designs of the equipment required by the approaches were developed.

Interfaces between SEPS and other STS elements and payloads were identified and defined to the extent warranted by the present level of design definition of the elements, (or to the extent necessary to identify the desirable characteristics of the interface).

Assessments were conducted of technology areas that would have significant influence on the recommended SEPS and GPME configuration or on their operational modes with the STS.

Task V original study requirements were to update NASA supplied "baseline" SEPS program costs by generating cost deltas resulting from the study recommended changes to SEPS baseline subsystem. Recommendations from this study and NASA in-house activities indicated that the baseline would be so changed that cost delta related to it would not be meaningful. A better approach to costing was to generate new independent cost estimates. Estimated program costs were significantly reduced by new configurations and new operational modes evolved during this study.

1.5 STUDY LIMITATIONS

The range of technical, operations, and programmatic factors the study covered was quite broad. Effort was therefore concentrated largely on decision controlling factors. Many interesting but nondecision critical details could not be investigated.

Certain areas of the study were limited by the following guidelines or constraints:

- Cost effectiveness of SEPS was limited solely to STS transport cost savings for accomplishment of "The October 1973 Space Shuttle Traffic Model," NASA TMX-64751, Revision 2, dated January 1974. No cost advantage of other SEPS mission capabilities such as on-orbit servicing, maneuvering payloads in orbit, or the great increase in allowable payload weights for high energy earth orbit missions and planetary missions was considered. The mission model covers the years from 1981 to 1991.
- The "baseline" STS was defined as the Shuttle, an expendable transtage (IUS) through 1983 and the MSFC (June 1974) baseline Tug from 1984 to 1991.
- Planetary mission roles were not investigated except to ensure that configurations and characteristics defined for the SEPS earth orbital functions would provide equal or enhanced planetary mission capabilities relative to the NASA supplied baseline SEPS configuration.

Section II

SIGNIFICANT SYSTEM CHARACTERISTICS AND STUDY CONCLUSIONS

Solar electric propulsion stages have radically different physical and performance characteristics than the familiar chemical propulsion stages. These characteristics influence every facet of the associated development and operations phases. Although the difference in physical characteristics is rather obvious, the tremendous potential gains from exploiting those differences (and some limitations) are often overlooked even by experienced space system planners and concept evaluators.

Depending upon the evaluator's recognition of the influence of certain physical and performance differences of SEPS and conventional stages, the conclusions and other results of this study may be accepted as so obvious as to hardly warrant their statement, or may be summarily rejected.

Because of these factors, the following rather unorthodox order of presentation will be used:

- Primary characteristics and resulting first order influences of system differences
- Study conclusions
- System concepts and data generated
- Technology assessments.

2.1 PRIMARY CHARACTERISTICS AND INFLUENCES

Isp AND THRUST

The feasible range of specific impulse (Isp) for mercury ion systems is 2,000 to 30,000 seconds. Demonstrated designs for SEPS operate in the 2,000- to 5,000-second range. For negligible weight and cost penalty, selectable high thrust and low Isp, or high Isp and low thrust operating modes can be designed into the system. Selection of the combination best suited to each mission phase can be made in flight.

The potential of SEPS high Isp can be inferred from the following comparisons. A characteristic high performance (450-second Isp) Space Tug configuration with 22,676 kg of O_2/H_2 propellants and a 2,585 kg inert weight can provide a 1,814 kg payload a 8,016 m/sec change in velocity. A 3,000 second Isp SEPS with 959 kg of mercury propellant and a burnout weight of 1,247 kg can provide the same ΔV to a similar 2,585 kg payload. The SEPS loaded weight (2,206 kg) is only 9 percent of the chemical stage weight 25,260 kg.

That ΔV is approximately the ΔV for a round trip from Shuttle orbit to geosynch and return. If that were the mission and SEPS executed it, SEPS low thrust would result in "gravity losses" such that its idealized Δ requirement is 1.5 times an impulse stage's ΔV or 12,024 m/sec. For the SEPS to accomplish that ΔV its initial weight would be 2,794 kg (11 percent of the chemical stage mass) and it would have to tank 1,516 kg of Hg.

The specific impulse of ion thrusters is proportional to the square root of the screen voltage ($\sqrt{V_s}$). SEPS specific impulse can be increased by operating at higher thruster screen voltages. Assume we operate at two times the screen voltage of the 3,000 sec SEPS. Isp is now $\sqrt{2} \times 3,000$ seconds = 4,243 seconds. Initial stage weight is only 2,273 kg, and only 1,026 kg of Hg had to be tanked.

SEPS receives its energy from the sun, so increasing the energy per unit mass of propellant (increasing Isp) in order to reduce the total required propellant for a mission will reduce the initial total weight, but will increase the mission time. To shorten trip times, SEPS energy collection and conversion rate to electrical power must be increased. Within ranges of interest for SEPS, power is limited only by the cost of solar arrays required to produce the higher power levels. Masses increase but they are within launch capability of STS single flights for SEPS range of interest.

As a result of the physical phenomena by which SEPS functions, it has the unique capability to trade increased mission accomplishment time against reduced gross weight as was just illustrated. Its mercury propellant is so dense (specific gravity over 13) and tank pressures so low (703 kg/m^2) that

excess capacity tanks can be designed into the systems for a minor increased inert mass penalty. If this is done, unexpected increases in payload masses or more demanding total impulse missions, not originally planned for the SEPS, can be accomplished simply by allowing longer times for accomplishing the missions and tanking more propellant at initiation of the mission.

In the power ranges desirable for the 1984 to 1991 time frame (25 kw up to 100 kw), the power level chosen for development has relatively small influence on the development cost of the system. SEPS capability as a transport stage is almost directly proportional to its power level in the range of interest.

Solar arrays do represent a significant part of the production cost of the complete stage at present day solar cell prices. As indicated in subsection 2.7, increased power levels also enhance planetary mission capabilities.

BASIC PROPULSION POWER CONVERSION CONSIDERATIONS

The SEPS thruster is a simple electrostatic charged particle accelerator as shown schematically on Figure 2-1. The operating Isp, proportional to $\sqrt{V_s}$, is set by the voltage level of the screens. The thrust level and current flow are dominantly responsive to the ion density of the plasma in the internal enclosure of the thrusters. Therefore, primary thrust control is by control of the temperature of main and cathode mercury propellant vaporizers which will determine the plasma pressure inside the thrusters.

Of the total electrical power to the thruster, 80 to 90 percent (depending on screen voltage) goes into ion beam energy. This "screen power" needs to be direct current, relatively free of ripple currents and at approximately the voltage corresponding to the Isp desired for the particular mission or mission phase. The solar arrays are nearly ideal sources for direct supply of this power. Their use avoids loss of power due to processor inefficiencies and reduces weight and cost associated with screen power processing. Volume II, subsection 6.7 discusses related factors in more detail.

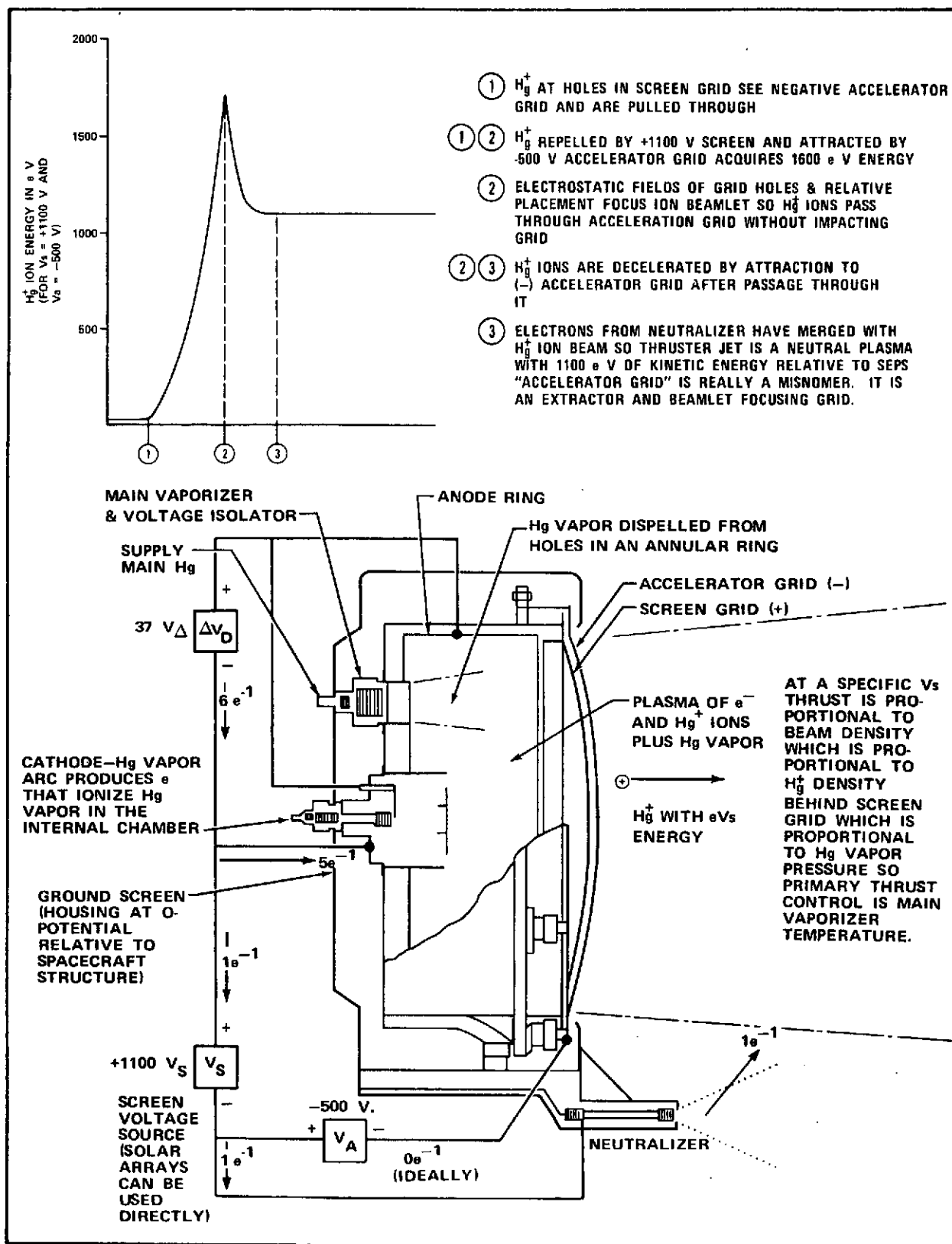


Figure 2-1. SEPS THRUSTER SCHEMATIC

PHYSICAL SIZE AND TEST CHARACTERISTICS INFLUENCING SUPPORT REQUIREMENTS

The SEPS dimensions when packaged for transportation or in the launch configuration are 3m by 3m by 5m. A variety of surface or air transport options exist for transport from manufacturing site to operations support center and to launch site without requirement of special vehicles or handling gear.

The SEPS is essentially an electrical device with relatively simple mechanical subsystems. No expensive test devices, other than vacuum chambers now in existence and used only for initial thruster subsystem acceptance tests and for Design, Development, Test, and Evaluation (DDT&E) tests, are required. The operational and sustaining engineering force and facilities required for SEPS total program support is therefore small.

2.2 THE SPACE TRANSPORTATION SYSTEM WITH SEPS AS A TRANSPORT ELEMENT

The system elements are shown on Figure 2-2. No physical changes or additions to the Shuttle are required for SEPS operation in the system. A standard family of "kick stages" should not be defined until more detail exists on the

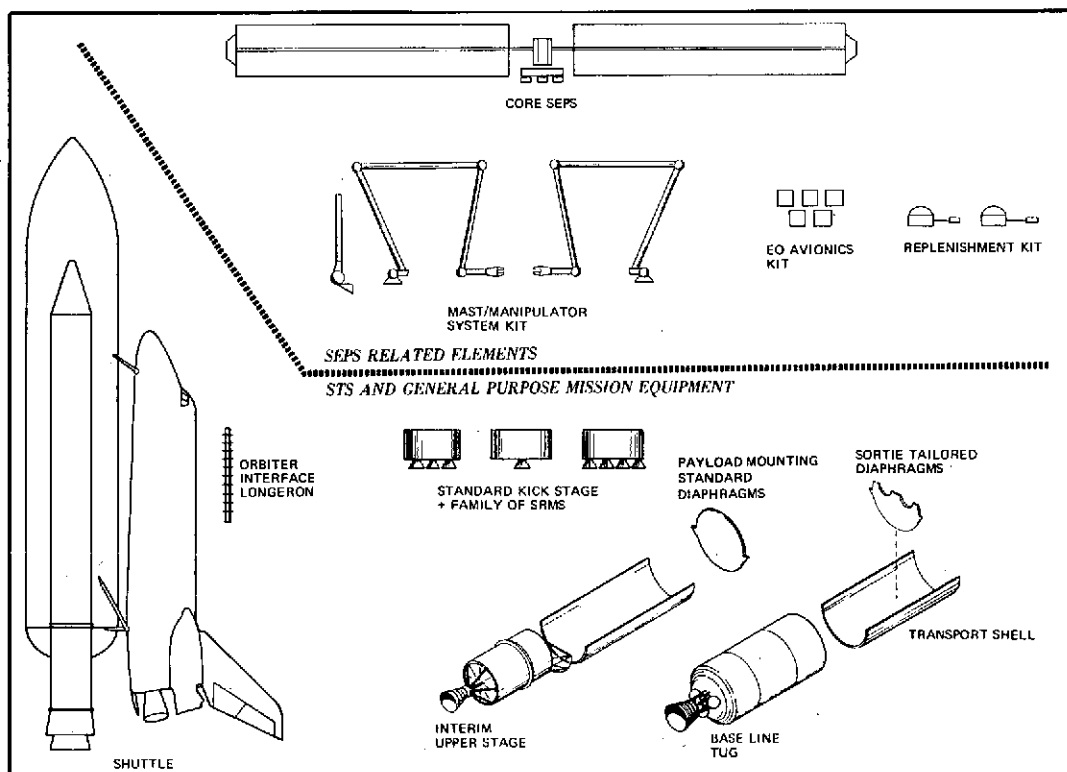


Figure 2-2. STS WITH SEPS SYSTEM ELEMENTS

character of payloads and specific mission requirements. For this study, a representative kick stage that could be fitted with different numbers of solid rocket motors was assumed. For earth orbital missions, SEPS eliminates the need for any kick stages or payload velocity addition ability in the payloads themselves for achieving initial mission position; or for retrieval of payloads after mission accomplishment. For other missions, planetary and earth escape, SEPS reduces auxiliary propulsion performance requirements without placing any demands or constraints on the kick stages. SEPS offers the potential for recovery of Tug instead of expending it for many missions, but the scope of this study did not allow investigation of that potential.

The study ground rules supplied by NASA defined an Interim Upper Stage (IUS) which is a "stretched tank" transtage for use through 1983 and a baseline Space Tug defined by MSFC for use from 1984 onward.

SEPS requires no characteristics of these vehicles that are not required for their missions when operated independently of SEPS. Because SEPS can always accomplish the remaining portions of any combined SEPS plus IUS or Tug missions by extending the trip time, SEPS removes the development schedule and cost risks that are associated with meeting burnout weight and propulsion performance goals from the IUS and Tug programs.

The system characteristics and programmatic cost factors identified in this study indicate that a single core SEPS vehicle should be developed. NASA has directed that this study concentrate on the operations characteristics of a 25 kw power level SEPS. NSI, for reasons to be described later under principal trade studies, believes that greater power levels are desirable. Except for trade study discussions, all SEPS configuration, performance, and operations characteristics discussed in this volume are those of a 25 kw power level configuration.

The core vehicle is produced in a single continuous production run to minimize production cost of the 11 flight articles and one test article which is refurbished to provide the second spare vehicle for the program. There are eight SEPS committed to planetary missions, two to earth orbital missions,

and two as program spares counting the refurbished test article spare as a spare. The four planetary missions, accomplished with the SEPS back-to-back flights are: 1981 Encke Rendezvous, 1981 Jupiter Orbiter, 1986 Asteroid Rendezvous, and 1987 Mercury Orbiter. For some planetary missions the core vehicle is fitted with a larger phased array antenna and some mission specialized sensors. The communication, navigation and guidance, and data management subsystems of the core vehicle are standard although they are operated in different modes for the planetary mission and the earth orbital missions. Major blocks of the software are naturally different.

The extendable payload mast and manipulator system kit for earth orbital operations provides near universal adaptability for in-space handling, servicing, retrieval, and maintenance of payloads without forcing severe configuration or geometric arrangement constraints on payload developers. The total mass of the subsystem is 126 kg. Programs and specific sortie data stored with SEPS control computer prevent human operators from commanding manipulator functions that could cause equipment damage and allow simplified manipulator hand steering to desired locations. The combined mechanisms required for the full range of payload servicing, maintenance, and multiple payload transport functions is simpler with manipulators than with any other system that provides even the basic capabilities in each of the stated areas.

For the earth orbital kit the avionics system contains four TV cameras, two located on the manipulator arms and two located on the scanning platforms with other core vehicle navigation and guidance sensors. The earth orbital function utilizes a scanning LADAR for rendezvous with payloads and other elements of the STS. The core SEPS is capable of autonomous navigation and guidance on planetary missions. With the addition of horizon sensors or an Interferometric Landmark Tracker (ILT), the SEPS has autonomous navigation and guidance capability for earth orbit missions. SEPS can establish its position to about 1 kilometer and its velocity to about 0.1 meter per second.

Economy of STS operation to accomplish the total NASA supplied reference mission model in the years 1981 to 1991 demands multiple payload deployments on each Tug-Shuttle flight. For example, 83 percent of the payloads requiring upper stages can be arranged in flight manifests for a Shuttle comprising five

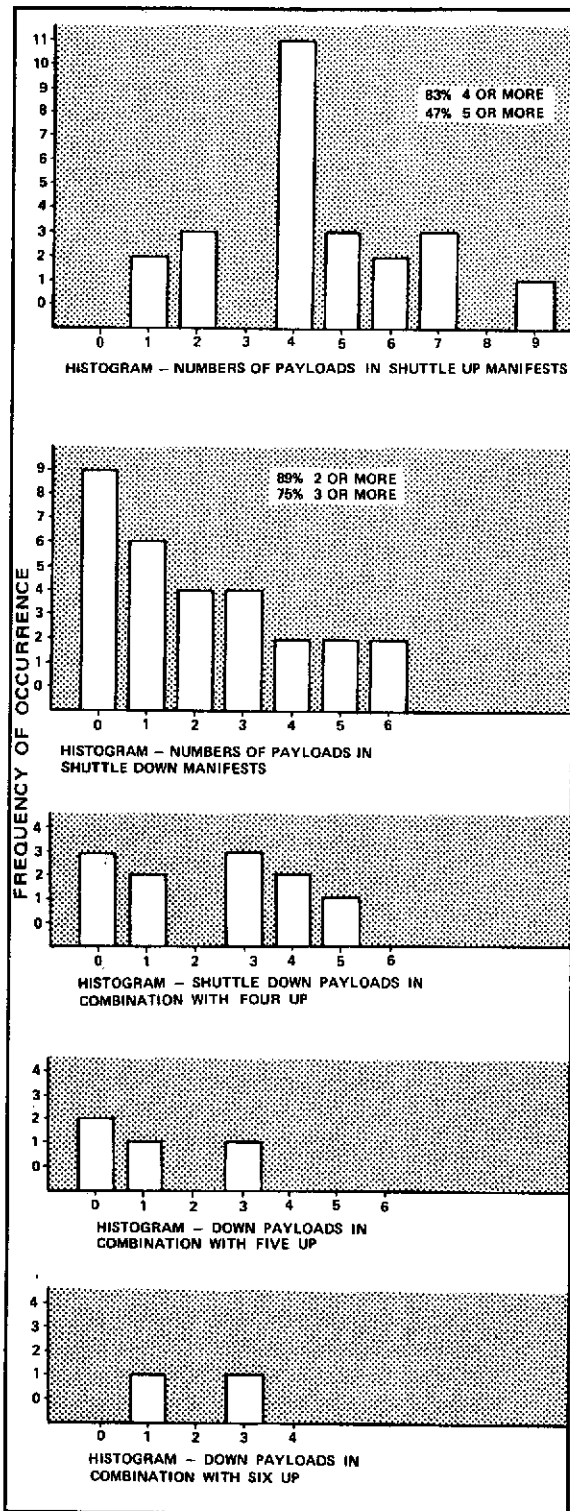


Figure 2-3. FREQUENCY OF OCCURRENCE
VERSUS NUMBER OF INDIVIDUAL
PAYLOADS IN CARGO MANIFESTS

or more individual payloads. Figure 2-3 shows frequency of occurrence of Shuttle flight manifests versus number of individual payloads on the manifest. On some flights some of these individual payloads go to intermediate orbits and are not transported by SEPS.

In order to isolate Shuttle and Tug operations from the potential delays of launch preparation associated with integration of four or more payloads into a single launch package and to provide payload users with simple, easy access to their payloads, NSI generated the standard transport shell and payload mounting diaphragm concept shown on Figure 2-2. This concept allows all payloads for a specific flight to be integrated into a single package prior to mating the package to the Tug. The Tug plus "package" is then mated to the Orbiter as a single payload.

Since each payload is mounted directly to a diaphragm, interactions between the individual payloads are minimized, and access to individual payloads is simplified.

The payload transport shell is a lightweight half cylinder, honeycomb core, monocoque structure. To meet the Orbiter crash safety load requirement (9g longitudinally) without causing

large weight increases in the Tug, the shell is designed to transmit inertial loads from the masses attached to payload mounting diaphragms to the Orbiter's payload support longeron through an adapter longeron. This adapter longeron distributes the inertia induced crash loads over some 9 meters of Orbiter longeron on each side of the Orbiter's cargo bay. Each individual fastener load remains within the Orbiter design limit.

The adapter longeron shears the 9g longitudinal crash load out through 9 meters of corrugations along each upper edge of the payload half shell. No concentrated load points are required between the adapter and the shell, therefore minimizing shell weight. The transport shells can be designed to have splice provisions so that short shells can be flown. The standard diaphragms for payload mounting have multiple payload mount structural attach points and are reusable GPME. Specially tailored payload mount diaphragms are fabricated for those infrequent conditions where unusual payload attach requirements exist.

By NASA direction, for program planning purposes SEPS is assumed to have an operational onorbit lifetime of 5 years or the lifetime dictated by accumulation of 20,000 operational hours on each thruster. Commercial satellite systems are presently being designed for 10-year onorbit lifetimes. SEPS vital function subsystems either have inherent high levels of redundancy (thruster subsystem and arrays) or can be designed for both high redundancy and high reliability. Because of SEPS' high specific impulse propulsion system, weight increases that serve to increase reliability can be readily accepted. If a diligent technology program aimed at increasing thruster lifetime is pursued, NSI believes SEPS potential onorbit lifetime can be extended to 10 years.

SEPS has only two expendables, the main propellant (mercury), and the attitude control system propellant ($N_2 H_4$). Both propellant supply subsystems are N_2 accumulator pressurized so that replenishment may be accomplished by simply forcing propellant from the replenishing tank into the depleted storage tanks which recompresses the expulsion gases during the replenishment. The SEPS manipulators provide the inherent ability for self-servicing on any payload delivery mission where Tug brings an expendables replenishment kit up with the payload group to be transferred to SEPS. SEPS should be developed for in-flight replenishment of expendables to exploit its potentially high reliability and its 5- to 10-year operational lifetime.

2.3 SEPS CONFIGURATION AND FUNCTIONAL CHARACTERISTICS

The foregoing discussions described the elements composing an STS plus SEPS transport system. At the beginning of any discussion on SEPS configuration, several factors should be emphasized. The active elements of SEPS are very compact. Once operational in space the greatest acceleration that SEPS is ever exposed to results from its attitude control system thrusters. Their absolute thrust level requirement for control docking is extremely low. The level is therefore chosen based on accelerations that make for operator convenience and reduce the time that mission control centers must be involved in SEPS operations. Peak accelerations from the ACS system thrusters are in the range of 0.002 to 0.01 g depending on the masses of attached payloads and on-board propellant. Any desired deployed geometry in space can therefore be implemented at a very small penalty in structural mass increase. The active elements of SEPS have no preferential orientation except to meet the condition that solar arrays should be oriented normal to the sunline and radiation cooling panels should be oriented to dark space for nominal cruise conditions. Many equally attractive arrangements of SEPS power production and thrust producing components are possible.

The decision controlling factors regarding SEPS overall characteristics, therefore, are primarily related to the functional interfaces with payloads and STS General Purpose Mission Equipment (GPME). In summary form, the decision controlling factors are:

- STS transportation efficiency depends on multiple payload deliveries and multiple retrievals
- Cost effectiveness requires that GPME be usable on successive flights without modification and with few special payload adapter items
- The GPME must simplify Shuttle-Tug operations
- Multiple payload transport must place minimum constraints on payload designers
- SEPS staytime in space is limited only by wear out. To exploit this capability the design should provide for easy replenishment of expendables
- GPME mass increase to simplify other STS operations does not reduce SEPS + Tug net payload capability; modest trip time increases allow SEPS to makeup for Tug's lower payload transfer orbit ability

- SEPS capabilities are almost directly proportional to design power level in the range from 20 to 100 kw. In this power range, development costs are only slightly influenced by power level.

With the characteristic controlling factors identified, selection of criteria for choosing a SEPS configuration must be established. Configuration in this context refers to what characteristics are to be implemented and at what power level for thruster subsystems. These criteria derive from national and NASA policy decisions rather than technical fact. No configuration choice is defensible without final reference to these criteria. The configuration selection criteria are to configure for:

- The minimum to meet absolute mission needs or some reference mission model existing on a certain date, or
- Cost effectiveness against a reference mission model considering only transport vehicle operational cost savings, or
- Configure for total cost effectiveness plus those low cost characteristics that greatly enhance functional capability and mission versatility, since mission models and payload concepts are at present inadequately defined and are constantly changing as the value of new missions and concepts are recognized.

Based on the analyses of this study, the foregoing decision factors, and NSI's belief that the third criteria above is the logical criteria choice, the conclusions regarding SEPS configuration and Space Transportation System GPME associated with SEPS sorties are:

- A standard payload transport shell to facilitate Tug handling of independently mounted multiple payloads should be developed.
- A manipulator/extendable payload support mast system for SEPS will result in low operational cost and impose the minimum design constraints on payload developers.*
- Screen power direct from the solar arrays with inherent Isp option to match specific mission requirements will reduce the size of required solar arrays for a given thrust, improve reliability, and reduce thermal control panel size.

*A detectable mission kit of these items for Tug would provide desirable capability for quick response services.

- SEPS transportation capability within a specified trip time is almost directly proportional to power. SEPS development costs are only slightly increased by power level and operational costs are reduced. SEPS should be developed with a power level of 50 kw or more.

The basic configuration recommended for SEPS and GPME is shown on Figure 2-4 which shows the transfer of a set of payloads from IUS to SEPS payload transport mast. Figures 2-5 and 2-6 show additional details. To illustrate the recommended system's capability, one of the sorties from the baseline 25 kw SEPS System Operational Profile will be briefly described. The sortie is sortie No. 4, and it begins in January of 1983. The Interim Upper Stage (IUS) brings 7 payloads up to payload transfer orbit to meet SEPS. The 7 net payload masses SEPS will deploy at its final mission destination total about 3,860 kg. The envelope dimensions of the payloads are as defined in the NASA supplied reference mission model are depicted as various size cylinders on Figure 2-4.

The expendable IUS without SEPS could deliver only about one-half this net payload weight to geosynchronous orbit and would have to deploy all payloads at one point. Each payload would therefore have to be designed to independently maneuver to its final mission destination. Without SEPS, two IUS plus Shuttle flights would be required to deploy these seven payloads.

After completion of sortie #3 SEPS had been dormant in geosynchronous orbit awaiting commands to initiate sortie #4. The SEPS cruises down to the elliptical rendezvous orbit (18,520 km perigee by 47,967 km apogee) was initiated some 17 days previously. In accordance with the mission plan, Shuttle with IUS and payloads was launched and through the standard mission procedures IUS was targeted on the known conditions of SEPS. IUS achieves the target conditions within its navigation and guidance system accuracy.

Ground track may order an IUS correction or SEPS may initiate final rendezvous action immediately after acquisition of IUS by SEPS TV systems, or by the laser radar (LADAR). These systems have acquisition ranges of approximately 7,223 and 2,593 kilometers respectively, in passive acquisition modes with the targets are sunlit.

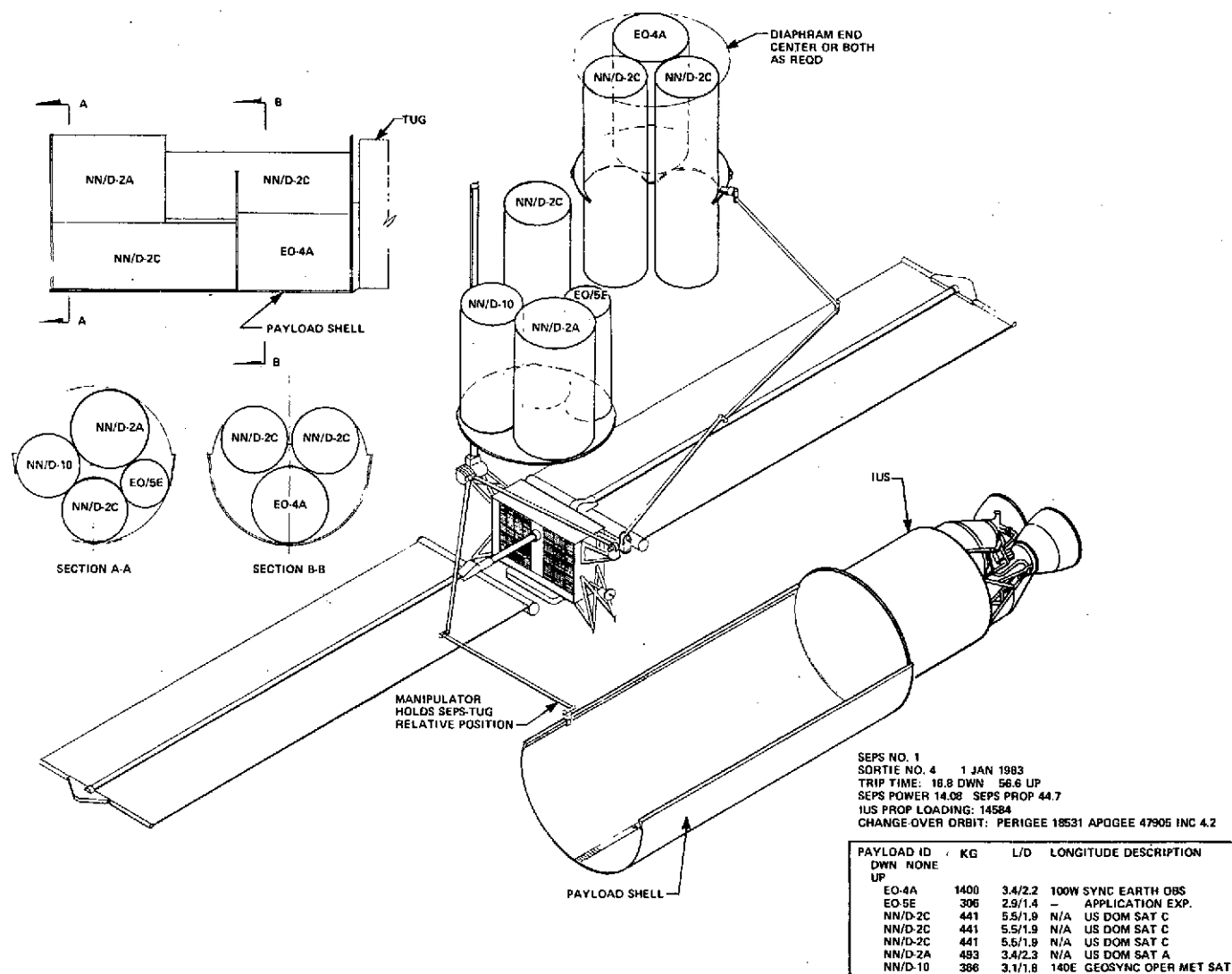


Figure 2-4. PAYLOAD EXCHANGE SORTIE NO. 4

2-14

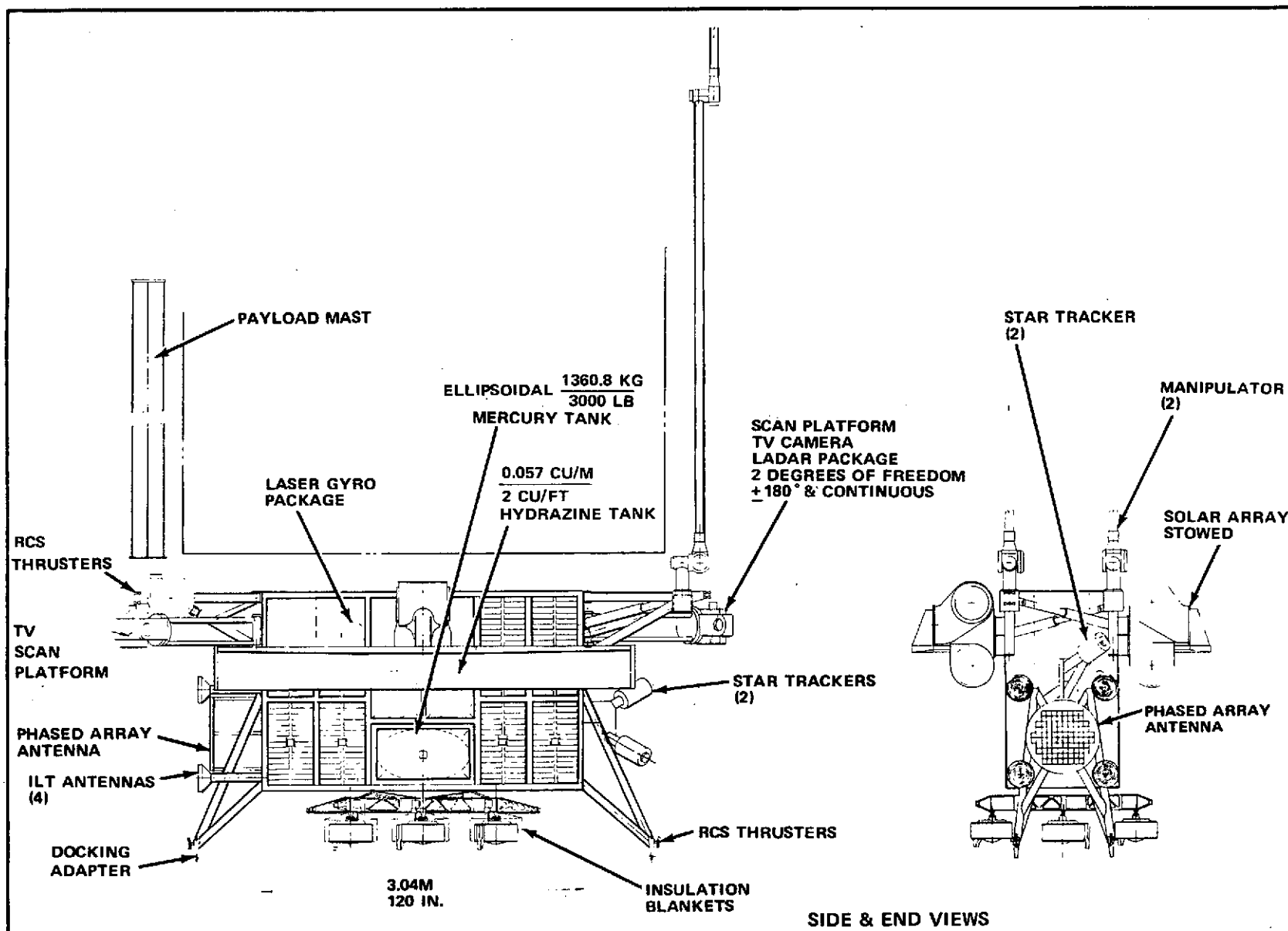


Figure 2-5. RECOMMENDED SEPS CONFIGURATION

2-15

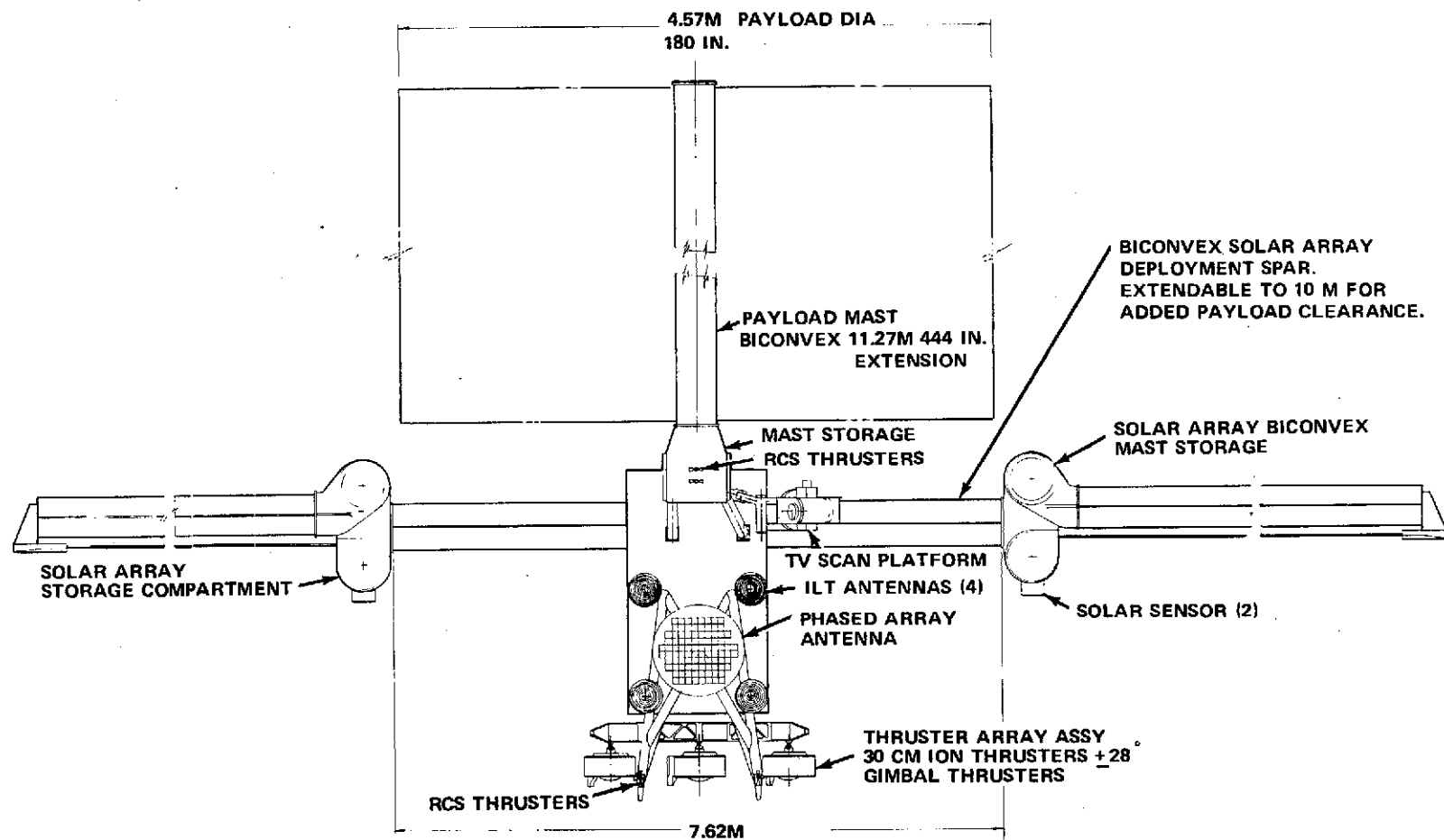


Figure 2-6. RECOMMENDED SEPS CONFIGURATION

To shorten rendezvous times SEPS will use a combination of its chemical Attitude Control System (ACS) and ion propulsion system thrusters. SEPS will be the active partner in the rendezvous and payload transfer operation with IUS.*

SEPS closes on the IUS which is passive but in an attitude hold mode. Closing is based on range, range rate, and line of sight data from the LADAR and the scan platform mounted TV system.

At the option of the SEPS Operations Center (SEPSOC) flight control final approach maneuvers are controlled by onboard systems in an autonomous manner or by a payload transfer controller in SEPSOC.

Final closing is accomplished in a parallel or other nonintersecting velocity vector mode so that human or other errors cannot result in catastrophic collisions. When on station alongside Tug or IUS, the ground command pilot steers a manipulator end effector (hand) out to position to grasp the payload shell. Views from TV cameras, body mounted on SEPS and on each manipulator arm, are employed as visual aids in accomplishing this action. After the manipulator "hand" grasping the payload shell has been clamped, the attitude control system of both vehicles are deactivated to conserve propellants. If a preferred space orientation is desired for any reason, such as a special lighting effect, one of the vehicle's ACS would hold attitude. The manipulator arm holds the vehicles in their original relative geometric positions.

The other manipulator hand is steered to one side of the transport shell to release the latch holding the diaphragm to which the first group of payloads are mounted. The manipulator then deploys a payload mast clamp on the diaphragm, releases the payload umbilical through which the IUS/Tug supplied the payload electrical and data system connections, and then releases the diametrically opposite latch and grasps the diaphragm for transfer of the first load set to the payload transport mast.

**For this operation with Tug, Tug will be the active partner until station alongside SEPS at 100 to 300 meters is achieved. After this time SEPS is the active partner until completion of the mission.*

The payload transport mast comprises a pair of preformed biconvex sections edge welded so that, when wound on a drum, the edge welded sections collapse into parallel metal ribbons held on the drum by the combination of winding tension and forces resulting from the geometry of the housing. When the drum is driven in the (unwind) extend mast direction the ribbons spring to their preformed shape. The biconvex sections designed by rigidity criteria are surprisingly strong in bending (3,360 nautical miles) and have high torsional rigidity because of the edge welding of the ribbons. Nominal loads from ACS firing and diaphragm attachment are about 3 percent of this capability.

This payload transport mast is commanded out to any position required for the mounting of both payload sets. The diaphragms have spring loaded clamps that lock onto the mast when pushed against it.

The manipulator grasps the diaphragm containing the first payload set at a location where the TV camera on the arm can be slewed so that its field of view contains the diaphragm edge where the mast clamp is located. The payload transfer controller (teleoperator) commands the manipulator to lift the payload set out and place it on the payload mast. The visual aids provided are the scan platform mounted TV on the mast side, the scan platform mounted TV on the manipulator side, the TV on the back of the manipulator hand holding the payload shell (which can be slewed to see along or into the IUS-payload shell) and the previously mentioned TV on the back of the manipulator holding the diaphragm.

The manipulators detailed joint motion and arm segment positions required to achieve "hand" motion along a desired path are controlled by the computer. The ground controller flies the "hand" in the sense that he commands translational rates of the hand and rotational rates about its three rotational axes. The computer also provides damage avoidance by forbidding any geometry of the arms that will cause contact of the arms to SEPS or payloads, or contact of the payloads being translated to SEPS elements or other payloads already mounted on SEPS. The computer also prevents acceleration of masses being

translated by the arms to velocities greater than those the manipulator system can break before the mass contacts any element of the combined spacecraft and payloads system.

The system has flexibility in the degree of automation which can be selected for any operation. For example, if after the first hand is steered to grasp the payload shell at the beginning of the transfer function, the grasp position is given to the computer along with the shell geometry, payload simplified geometry, initial diaphragm positions in the payload shell, and desired attach locations on the SEPS transport mast, then the computer from stored programs and stored SEPS geometry could execute the desired payload transfers without active participation by ground controllers. The man controller can override and perform a function or part of a function at any time and then return command of the transfer to the computer as long as he inputs to the computer what part of the total cycle he has completed while he controlled the system.

Trade studies which led to choice of this system as the simplest for the combined functions of transport, deployment, retrieval, transfer, and servicing of payloads are summarized in Volume II of this report, with a more detailed description of the design concept.

The manipulators provide SEPS an inherent capability for self-assisted replenishment of the ACS and mercury propellants. Design concepts for implementation of this ability are presented in Volume II.

After SEPS has completed the payload transfer operation, the manipulator still holding the payload shell and attached IUS is used to push the space vehicles apart so that neither vehicle's ACS thrusters are used. After the vehicles have separated adequately, if the mission were conducted with Tug, Tug begins preparation for initiating the phasing orbit and transfer orbit maneuvers to return it to the Orbiter.

SEPS initiates cruise mode. For the sortie payload group used on Figure 2-4, it requires 57 days to achieve geosynchronous orbit. SEPS' proposed navigation and guidance system comprised of IMU, Startrackers, horizon sensors, (or Interferometric Landmark Tracker), and sun sensor, all supported by a central computer, can autonomously navigate SEPS to position accuracies of about ± 1 km and $\pm .1$ m/sec of desired velocities. Given these autonomous navigation and guidance accuracies, the only demands on STDN during this 57-day period are weekly status checks on SEPS' actual status versus its predicted status.

Payload data requirements may dictate more frequent STDN data link usage. Many payload developers will have facilities such that for appreciable parts of the trip time direct communications with SEPS will be possible.

Because of SEPS' low acceleration it does not use phasing orbits, but it is started on trajectory profiles so that continuous thrusting for the minimum length of time will bring it to the desired rendezvous or payload deployment point. The terminal phase of SEPS approach to a target point for deployment of a payload (or to a rendezvous) is just an extension of the cruise phase as indicated on Figure 2-7a. For sunlit targets the SEPS, with information from the ground as to target payload position, can acquire the target at distances up to 3,900 nautical miles and begin path adjustments. Figure 2-7a shows the relative motion of SEPS approaching a target geosynch payload when only the ion thrusters are used in order to conserve ACS propellants. Times are times before station alongside the payload at relative velocity 0. The arrows indicate the direction of thrust. Figure 2-7b shows added details of the last few hours.

The flight control center would not need to be fully manned prior to about 2 hours before payload deployment or retrieval was to begin. Conversely, if it is desired to compress the last 6 hours of the operation, ACS thrusters can be utilized. These thrusters combined for additive thrust in the same direction as the ion system, provide about 100 times the acceleration of the ion system. ACS produced acceleration is $.02$ to 0.1 m/sec^2 depending on payload mass.

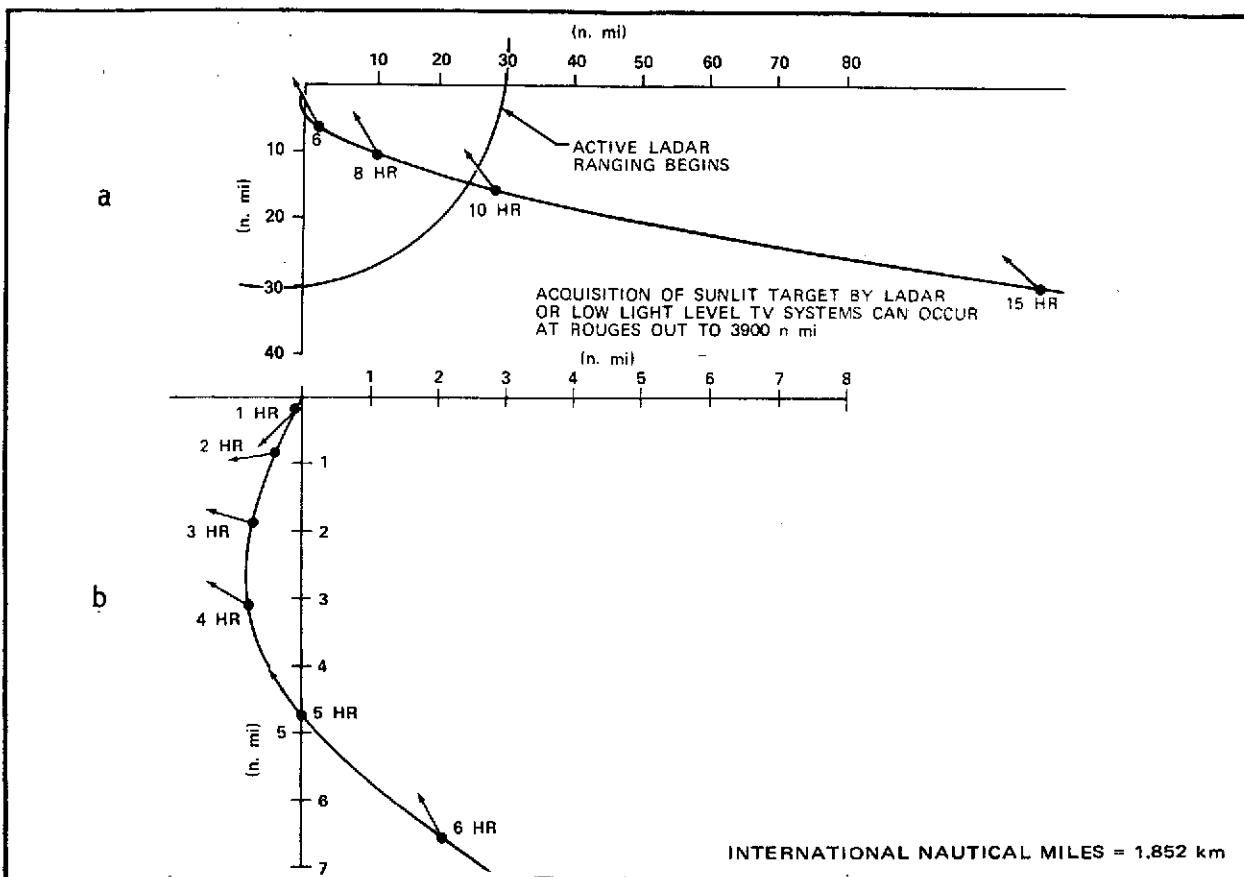


Figure 2-7. SEPS RELATIVE MOTION APPROACHING TARGET

2.4 MISSION ROLES FOR SEPS IN ACCOMPLISHING NASA REFERENCE MISSION MODEL

The reference mission model was derived from "The October 1973 Space Shuttle Traffic Model" (NASA TMX-64751 Revision 2 dated January 1974) by considering all flights from year 1981 through year 1991. SEPS functions in accomplishing the mission model are summarized as follows:

- SEPS/Tug combined missions to geosynchronous orbit with intermediate orbit payload deliveries comprised 124 payload deployments or retrievals which represented 93 percent of all geosynchronous payload missions and 47 percent of all intermediate orbit payload missions
- SEPS accomplishes four of the 16 planetary missions. Because backup planetary spacecraft are flown, the four missions require eight SEPS launches
- Tug alone accomplishes only 7 percent of the geosynchronous missions, but 53 percent of the intermediate orbit missions

- Low earth orbit missions are feasible for SEPS but we found no significant cost savings for this transport role.

A summary of the total mission model and SEPS utilization in accomplishing it is shown in Table 2-1.

Table 2-1. ACCOMPLISHMENT OF PAYLOAD MISSIONS
REQUIRING UPPER STAGES

Total Payload Missions	879
• Shuttle Only	644
• Requiring Upper Stage	235

MISSION CATEGORY	MISSION IN EACH CATEGORY	DIFFERENT PAYLOAD TYPES	TUG ALONE		TUG WITH SEPS RENDEZVOUS	
			No.	%	No.	%
GEOSYNCHRONOUS	133	17	9	7	124	93
ESCAPE	45	22	39	87	6	13
POLAR EO	33	5	33	91	0	0
HIGH ENERGY EO	9	3	9	100	0	0
INTERMEDIATE EO	15	2	8	53	7	47
TOTAL	235	49	95	40	137	58

Mission roles for SEPS with the Space Transportation System are seen to be predominantly in the geosynchronous orbit delivery, retrieval, and payload servicing area. In the study NSI was directed to establish cost effectiveness of an earth orbital SEPS strictly on the basis of direct transportation cost savings. Many other obvious benefits occur from SEPS capability. Direct transportation cost savings derive from the fact that with SEPS the required number of earth orbital Shuttle-Tug flights is 15 less than required to accomplish the mission model without SEPS. Other minor factors such as fewer expended IUS and kick stages result in a net transport cost saving of \$126 million after all earth orbital SEPS development, production, startup, and operations costs are amortized. The \$126 million saved represents a 217 percent return on the delta \$58 million investment in SEPS for earth orbital operations. These cost savings do not consider any of the special benefits which SEPS provides in addition to cheaper transportation service. The total STS with SEPS Operational Profile to accomplish the mission model is shown on Figure 2-8. The comparison of cost for all earth orbital STS transport functions with and without SEPS in the earth orbital role are summarized in Table 2-2.

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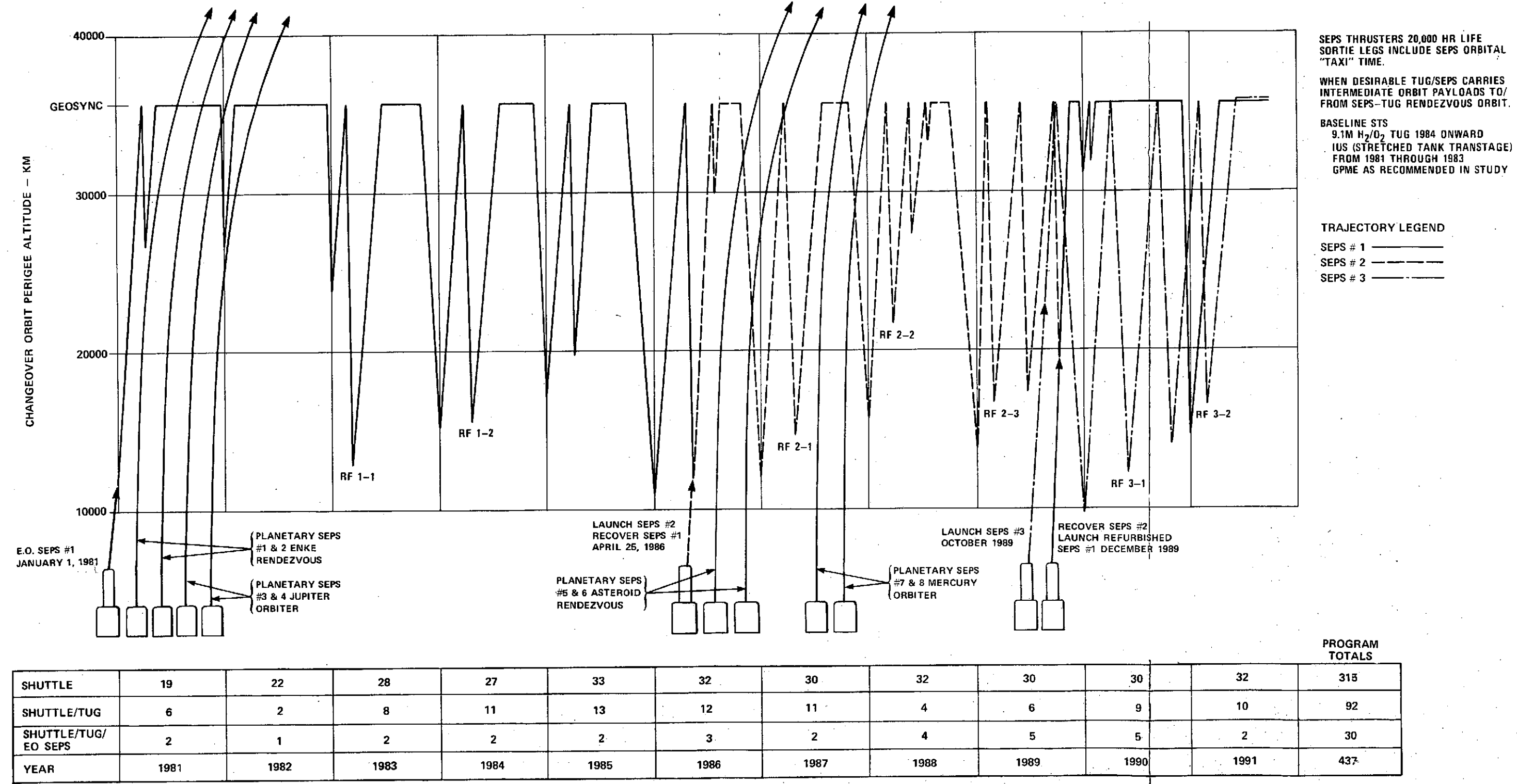


Figure 2-8. SYSTEM OPERATIONAL PROFILE (9.1-METER BASELINE TUG + 25 KW SEPS WITH 20,000 HOUR THRUSTER LIFE - REFUELABLE)

FOLDOUT FRAME

FOLDOUT FRAME

Table 2-2. STS COMPARED TO STS WITH SEPS FOR TRANSPORTATION COST EFFECTIVENESS -- EARTH ORBITAL FLIGHTS REQUIRING UPPER STAGES

COST ELEMENT (DOLLARS IN MILLIONS)	BLSTS		BLSTS BLSEPS (20 KHR-REFUELED)	
	10 ⁶ \$	NUMBER	10 ⁶ \$	NUMBER
SHUTTLE FLIGHTS @ \$11.09	1508.	136	1342.	121
IUS EXPENDED @ \$5.17	103.	20	98.	19
IUS WITH KICK STAGE @ \$6.37	13.	2	13.	2
TUG RECOVERED FLTS @ \$.96	87.	91	74.	77
TUG RECOVERED EXPENDED KS @ \$2.16	15.	7	15.	7
TUG EXPENDED @ \$14.16	0.	0	0.	0
TUG AND KS EXPENDED @ \$15.36	92.	6	92.	6
TOTAL TRANSPORTATION COST	1818.		1634.	
\$ SAVED IN TRANSPORT COST	--		184.	
VEHICLE INVENTORY COST SEPS @ (VARIES WITH PRODUCTION)	110.	9*	146.	11**
SEPS DEVELOPMENT & OPERATIONS	122.		144.	
TOTAL SYSTEM COST	2050.		1924.	
NET \$ SAVED	--		126.	

*8 PLANETARY VEHICLES PLUS ONE SPARE

**8 PLANETARY VEHICLES PLUS ONE SPARE PLUS TWO EARTH ORBITAL VEHICLES

In the above comparisons the STS operating without SEPS was given every advantage to assure that its full potential was utilized. No constraints were placed on Tug operating alone in regard to the number of payloads Tug could return in a single trip even though Tug would have to have equipment not presently planned for it that is capable of multiple payload retrieval. This equipment might be similar to a SEPS manipulator set plus a payload transport shell. Any of the practical alternates we investigated had nearly equivalent weight and complexity but a great deal less mission flexibility. Transport assumptions favorable to STS operating without SEPS in a transport role were:

- Tug payload transport and retrieval gear weight total was only 136 kg (more realistic weight penalties are 272 kg).
- All multiple payloads retrieval flights had payloads collected at one point by some arbitrary means, so Tug did not have to taxi around geosynchronous orbit to collect them.

- All multiple payloads to geosynchronous orbit were deployed at one location in geosynchronous orbit and the payloads provided their own propulsive power to move to their final mission locations.

In other studies conducted on STS without SEPS, various analysis groups have made arbitrary assumptions as to the payload packaging geometry that would be allowed for multiple payload flights and also as to the total number of up and down payloads to be allowed on one flight in order to reflect Tug's limited ability when not equipped with payload handling gear such as SEPS'. The effect of some of these assumptions on Shuttle flights required to accomplish the mission with and without SEPS as a transport element are shown in Table 2-3.

Table 2-3. COMPARISON OF STS FLIGHTS REQUIRED VS ALLOWED
PACKAGING SYSTEM TO ACCOMPLISH ALL MISSIONS
REQUIRING UPPER STAGES

STS VARIANT/PACKAGING SYSTEM	TANDEM	SIDE BY SIDE	THREE DIMENSIONAL	THREE DIMENSIONAL
BASELINE STS	156	150	150	136
STS WITH SEPS	146	129	125	121
STS FLIGHTS SAVED	10	21	25	15

NOTES: 1. Number of payloads for Tug operating alone limited to three up and one down on each sortie for all cases except those in the last column
2. General purpose mission equipment designs evolved in this study make any number of payloads per sortie feasible up to STS volume or mass limits
3. SEPS high performance essentially removes payload weight per sortie limits
4. Available payload volume in Orbiter cargo bay becomes the significant limiting factor.

NSI therefore believes that the cost saving equivalent to a reduction in Shuttle-Tug flight requirements by 15 flights is an extremely conservative estimate of transportation savings occurring from operation of the SEPS as an STS transport element. NSI believes that considerably more than the previously presented 217 percent return on EO SEPS development and operational startup cost investment would be achieved for actual operations conducted under the general management and operational concepts described in this study final report.

2.5 SEPS BENEFITS TO THE IUS, TUG, AND PAYLOADS

In addition to the transportation cost saving defined earlier, SEPS provides other programmatic cost savings and operational simplifications.

RELATIVE TO THE INTERIM UPPER STAGE (IUS)

- IUS flight preparations are greatly simplified. Payloads can be individually mounted into the transport shell. The multiple payloads in the transport shell package can be checked for flight readiness and combined with IUS in a single mating operation. IUS plus multiple payloads are presented to Shuttle as a single payload.
- It is feasible to recover IUS on many missions if it is equipped with the proper avionics equipment.
- The IUS if made recoverable is not required to have a navigation and guidance system capable of active participation in rendezvous operations. For SEPS rendezvous, IUS is targeted on SEPS and SEPS is the active participant. For return, the Orbiter is the active participant.

RELATIVE TO TUG

- Schedule and cost risk associated with high performance requirements of the Tug program are removed.
- Tug operations are simplified. Multiple payloads are presented to Tug as a single package ready for flight.
- Tug docking and payload interface, other than electronic may be developed for a single payload interface rather than for multiple docking and retrieval operations.
- Fifteen to 29 fewer Tug flights are required to accomplish the mission model.
- Tug does not have to be designed for the long staytimes in space necessary to perform orbital taxi missions for multiple payload deployment or retrieval.

RELATIVE TO PAYLOADS

- Reduction in transportation cost prorated to each payload. Average number of payloads per flight with SEPS is approximately four and for Tug alone is less than two.
- Essentially removes weight restrictions for payloads. Development cost increases to solve missed initial program weight goals will not be incurred.
- Higher initial payload weight allowances can be used to reduce development cost, improve reliability, or to provide for functional capabilities not feasible for payloads delivered by Tug alone.

- SEPS can deploy various payload elements (or refold them for retrieval) either as a backup to payload on-board systems or to relieve the payload entirely from self-deployment requirements. This should considerably reduce the development cost of some payloads.
- Most payload failures prior to end of design life are of the infant mortality type. SEPS can maintain station alongside a recently deployed payload with its TV cameras transmitting visual records of the payload's deployment and initial functional test responses to the payload developer's ground control commands. SEPS can assist in correction of the malfunctions. Upon ground command, SEPS can return the payload on the next rendezvous with Tug, if onorbit correction of the malfunction was not possible.
- SEPS can service payloads by providing for substitution of new sensor packs, or different experiments that may extend the usefulness of large optical or other instrument platforms without requiring their recovery or replacement in space.
- SEPS can provide replenishment services for payload expendables.
- For planetary missions, SEPS allows significantly greater payload mass and may provide power, communication, attitude, and thermal conditioning support to the payload. For some planetary orbiting payloads, SEPS can modify orbital parameters to conduct complete surface mapping operations plus mapping of fields and particle physical phenomena in space around the planet.
- Combination of science packages with SEPS can provide nearly ideal spacecraft for comprehensive surveys and continuous monitoring of earth's magnetosphere and near earth solar system space. "Out-of-the-ecliptic" missions are examples of the latter. New spacecraft do not need to be developed for these missions. SEPS itself may be considered a "standard" spacecraft.
- Where the scientific objectives require mission orbits so greatly separated in energy level that it is not practical to provide spacecraft propulsion to accomplish the change, SEPS can taxi the spacecraft to its new orbit thus saving a new Shuttle launch.

2.6 NEW MISSION APPLICATIONS FOR SEPS

This study, by work statement requirements, was directed primarily toward earth orbital mission roles, development of payload handling concepts, and analysis of operation support requirements. Roles in accomplishing the mission model with STS were described in some detail. Other potential applications of SEPS are:

- As a mobile spacecraft host supplying power to a direct broadcast, emergency communications satellite for remote oil exploration sites, or family units and villages in remote areas of the world. The system would provide one-way TV and two-way voice communication channels.

- Support and provide space mobility for a high resolution earth observing satellite providing high data rate real time information on weather or other local phenomena. High resolution optics and other sensors could switch systematically from locality to locality providing detailed scan information for each area for the time the local area was under observation.
- Collection of space debris and removal from frequently used areas of near earth space by return to ground via Shuttle and Tug or transfer by SEPS to higher infrequently used space areas.
- Transportation of very large space structures from their initial assembly positions in low earth orbit to final functional positions.
- Mobile teleoperated assembly device for construction of large space structures.

2.7 TRADE STUDIES AND TECHNOLOGY ASSESSMENTS

As in all systems, trade studies can be conducted at every level of the system's functional design detail. A principal objective of this study was to establish the first level trade of any system; namely, is its existence and operation justified on the basis of cost effectiveness, other identifiable benefits, and predictable future benefits?

The priority and scientific work of the planetary, cometary, and solar space exploration missions justifies initiation of the basic SEPS program. Investigations conducted during this study indicate that a reasonable case for initiation of the program can be made solely on the basis of its value for earth orbital missions and its cost effectiveness as an element of the Space Transportation System. NSI believes the combination of values for solar system exploration and earth orbital applications justifies high priority for early implementation of a SEPS development program.

Given a baseline SEPS, high cost effectiveness from its operation as an element of STS was established. Within the scope of this study it appeared that several major configuration trade studies and reassessments of baseline subsystem definitions were warranted.

The major trade study was evolution of the General Purpose Mission Equipment (GPME) concepts that simplify Tug operations with multiple payloads,

simplify Shuttle Orbiter interfaces, and also provide SEPS with a highly flexible payload support and servicing subsystem. The results of that study evolved the concept presented earlier. The key element of the concept was SEPS manipulator system. Alternate systems considered are described in Volume II. Considerations leading to the selection are summarized in Table 2-4.

Table 2-4. PAYLOAD SUPPORT, HANDLING, AND SERVICING
CONCEPT COMPARISON

ARTICULATED DOCKING FRAME AND ARTICULATED MULTIPLE PAYLOAD SUPPORT STRUCTURES	TRANSPORT SHELL, EXPENDABLE BOOM AND SIMPLIFIED MANIPULATOR	TRANSPORT SHELL, PAYLOAD MAST AND MANIPULATOR SYSTEM
ADVANTAGES	ADVANTAGES	ADVANTAGES
<ul style="list-style-type: none"> • SIMPLEST ONBOARD SOFTWARE 	<ul style="list-style-type: none"> • MODERATE ONBOARD SOFTWARE REQUIREMENT • SIMPLEST PAYLOAD TRANSFER FUNCTION 	<ul style="list-style-type: none"> • GREATEST INHERENT CAPABILITY FOR PAYLOAD SERVICES AND MAINTENANCE • MINIMIZES DESIGN CONSTRAINTS ON PAYLOADS • SIMPLEST AND MOST FLEXIBLE INFLIGHT OPERATIONS • SIMPLEST GPME & TUG PAYLOAD INTEGRATION FUNCTION • HIGHEST MISSION SUCCESS PROBABILITY
DISADVANTAGES	DISADVANTAGES	DISADVANTAGES
<ul style="list-style-type: none"> • MOST COMPLEX FLIGHT OPERATION • MOST COMPLEX FLIGHT HARDWARE • LIMITED GPME - REQUIRES TAILORING OF TUG MISSION EQUIPMENT & ORBITER TO PL ADAPTERS FOR EACH SORTIE • EITHER SERIOUS PL DESIGN CONSTRAINT OR VERY LIMITED SERVICING ABILITY • NOT ADAPTABLE TO UNFORESEEN OR UNPLANNED MISSION EVENTS • TOTAL COMPONENTS REQUIRING POSITIONING & FEEDBACK INFO EXCEED OTHER SYSTEMS 	<ul style="list-style-type: none"> • LIMITED SERVICING AND ONORBIT MAINTENANCE ABILITY • INTERMEDIATE ADAPTABILITY TO UNPLANNED MISSION EVENTS 	<ul style="list-style-type: none"> • ONBOARD SOFTWARE REQUIRES 32K WORD MEMORY STORAGE

CHOICE OF SEPS POWER LEVEL

The next most significant configuration definition choice is associated with SEPS power level. The decision becomes largely a matter of judgement since no clear mission requirement sets a definite minimum power level in the range of practical choices and no technology factor or cost factor produces a sharp step in development difficulty or cost as power increases.

The transport capability and operational flexibility of SEPS with the STS is almost directly proportional to power level. To demonstrate this, NSI developed complete System Operational Profiles for accomplishing the reference mission model. The 25 kw NASA baseline profile was shown on Figure 2-8. Figure 2-9 shows the sortie trip times required by a 25 kw SEPS to accomplish delivery and retrieval missions in conjunction with a 9.1-meter H_2/O_2 high performance Tug. The solid curves are the theoretical times required for SEPS to complete a mission with the maximum payloads that Tug could bring to the SEPS/Tug rendezvous orbit for the Tug one-way velocity increments shown by the abscissa.

The cross-hatched areas indicate the range of Tug velocity increments actually required to accomplish the mission model. The black dots are individual sortie trip times calculated with radiation degradation effects, and so forth. Figure 2-10 shows the sortie trip time savings of a 50 kw SEPS relative to the 25 kw SEPS. The system operational profile, as illustrated on Figure 2-8, does not utilize the full capability of a 25 kw SEPS until 1989 and does not require two SEPS on orbit until 1990. Therefore, use of a 50 kw SEPS saves only 2 more shuttle flights than a 25 kw SEPS. The advantage of increased power for earth orbital operations with the reference mission model is therefore due only to:

- Reduction of the time required for execution of individual sorties
- The speed with which SEPS could respond to unplanned revisions of flight schedules
- Quick response to special demands for maintenance and/or retrieval of malfunctioning satellite.

Conversely, the DDT&E cost to develop a 50 kw SEPS was estimated by NSI to be only 7.5 percent greater than for a 25 kw SEPS so that a very small additional investment produced a transport vehicle of nearly twice the inherent capability. Figure 2-11 shows a size comparison between 50 kw and 25 kw power level SEPS. Table 2-2 shows a summary of DDT&E cost breakdown with the incremental cost for development of the 50 kw system. Note that cost increase is essentially all in propulsion areas. The majority of that cost is due to the

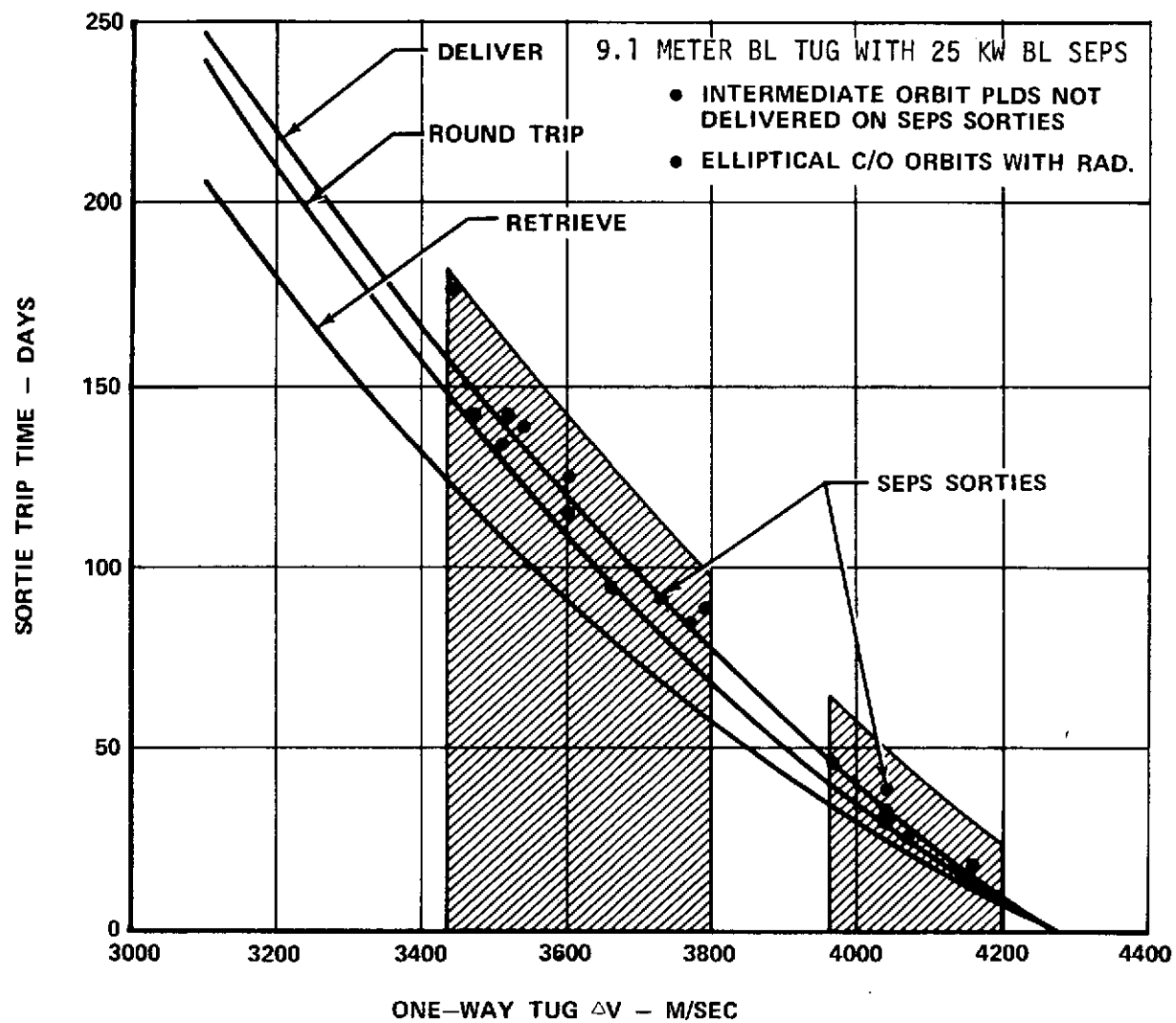


Figure 2-9. 25 KW 3000 Isp BASELINE SEPS SORTIE TRIP TIMES

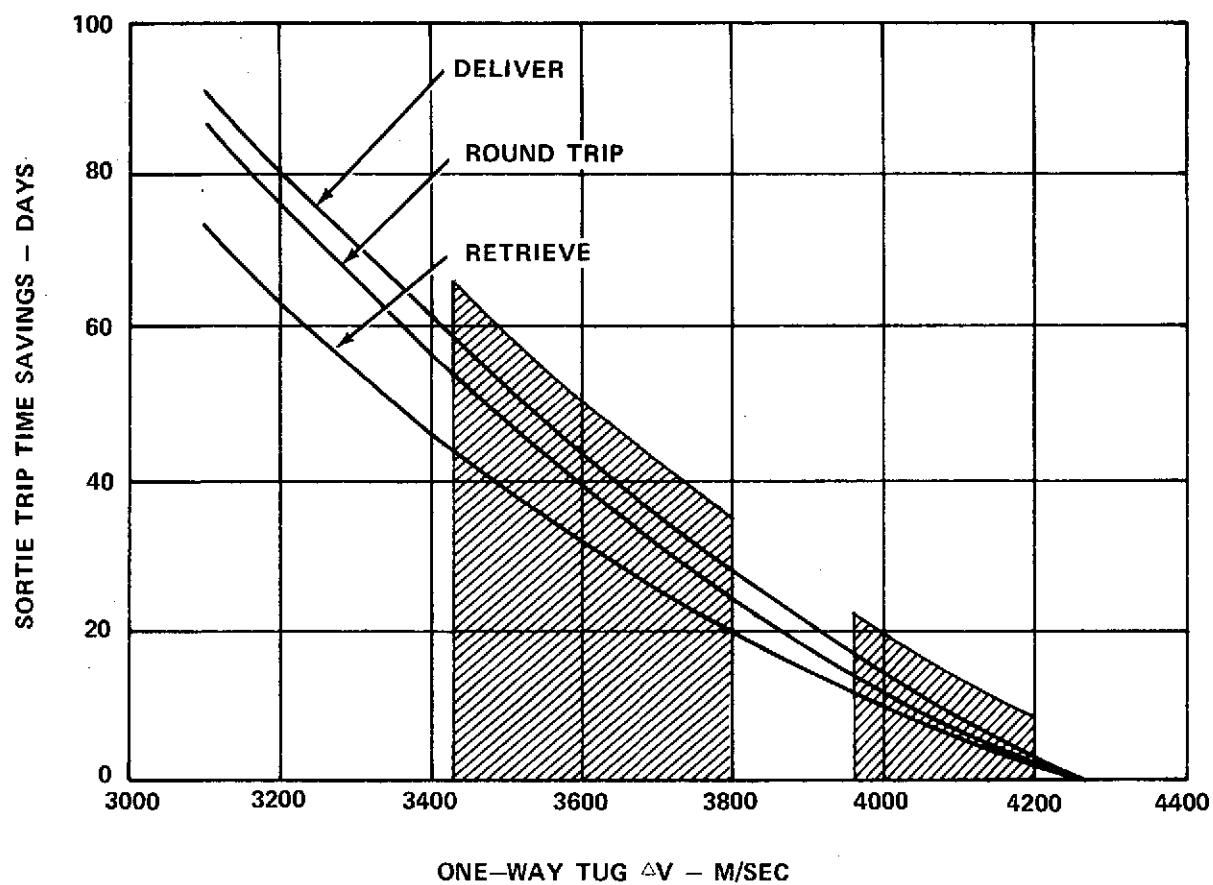


Figure 2-10. 50 KW 4243 Isp SEPS TRIP TIME SAVINGS RELATIVE TO THE 25 KW 3000 Isp BASELINE SEPS

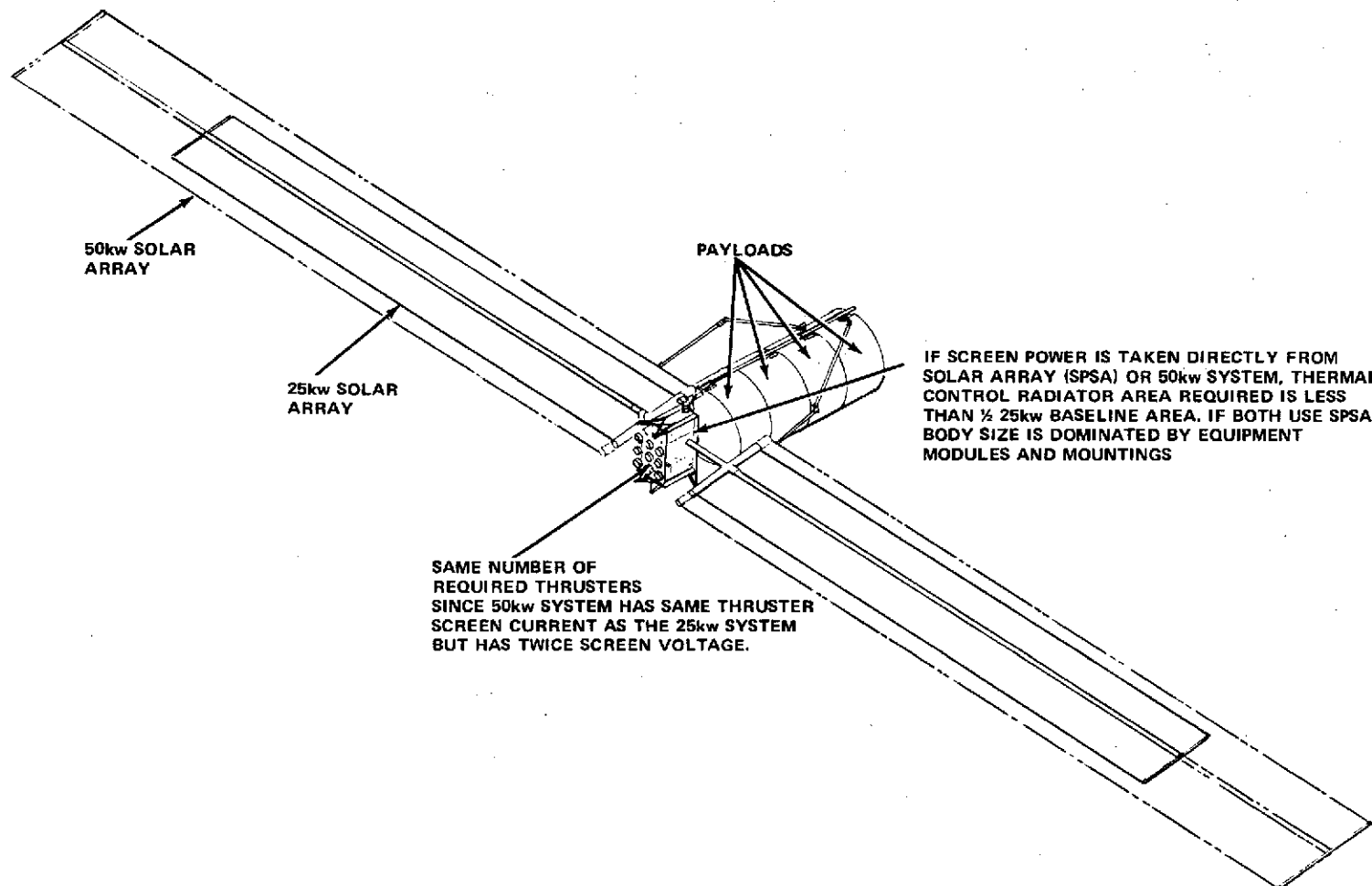


Figure 2-11. SEPS SIZE COMPARISON 25 KW 3000 Isp BASELINE TO
50 KW 4243 Isp SCREEN POWER SOLAR ARRAY

present high cost of solar cells which can be drastically reduced with a technology/production process program directed to cost reduction.

For the planetary missions the rate of gain in usable net scientific payload as power level increases varies considerably with the mission. In addition, the gains are sensitive to the mass-to-power ratio so that design approaches for SEPS thruster subsystem that result in high mass-to-beam power ratio or unjustifiably conservative mass estimates will cause apparent "optimum" power levels to be considerably lower than the true optimums. Even on the most conservative basis for mass-to-power ratio, such as used in Rockwell International 1972 and 1973 studies, trends for continuing growth in available net payload are indicated as power levels extend beyond 25 kw.

The planetary science packages conceived for most of these missions do not indicate the need for the higher payloads associated with the higher powers desirable for a SEPS operating in earth orbit. It is the opinion of this author at least, that the planned sciences packages are rather minimal and that a great deal more useful information would be obtained if the available payload mass allowed by the higher powered SEPS were used to fly on the planetary missions, some modification of the higher resolution, versatile sensors and instruments contained in proposed satellites such as the Synchronous Earth Observing Satellite (SEOS) and other environment determination and monitoring satellites. Figures 2-12a and 2-12b present a review of typical planetary missions from earlier SEPS work by Rockwell International. The curves that show parametrically the influence of trip time and power level, the ordinates labeled "Approach Net Mass" are all masses (SEPS nonpropulsive and gross payload) in addition to the mass of the solar arrays and the thruster subsystem. If a standard core SEPS were used as the spacecraft bus, the gross payload would be approximately net mass minus 500 kilograms. For the Jupiter Orbiter the payload must include the chemical retro rockets for capture maneuver into a highly elliptical Jovian orbit.

The four sets of mission charts demonstrate two salient features. In all cases, increased power increases payload. For the mission beyond 1 AU power,

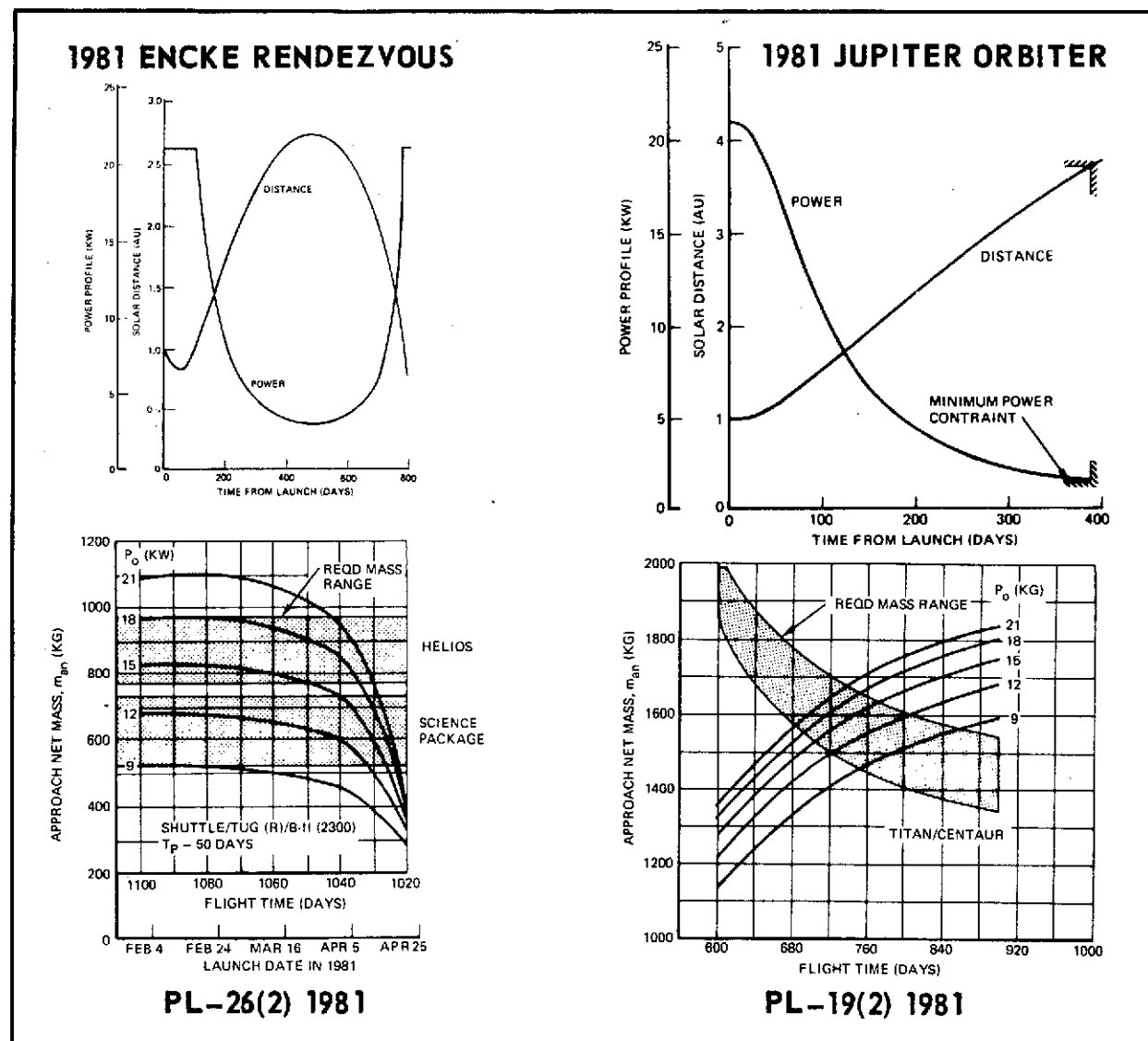


Figure 2-12a. TYPICAL PLANETARY MISSIONS - 1981

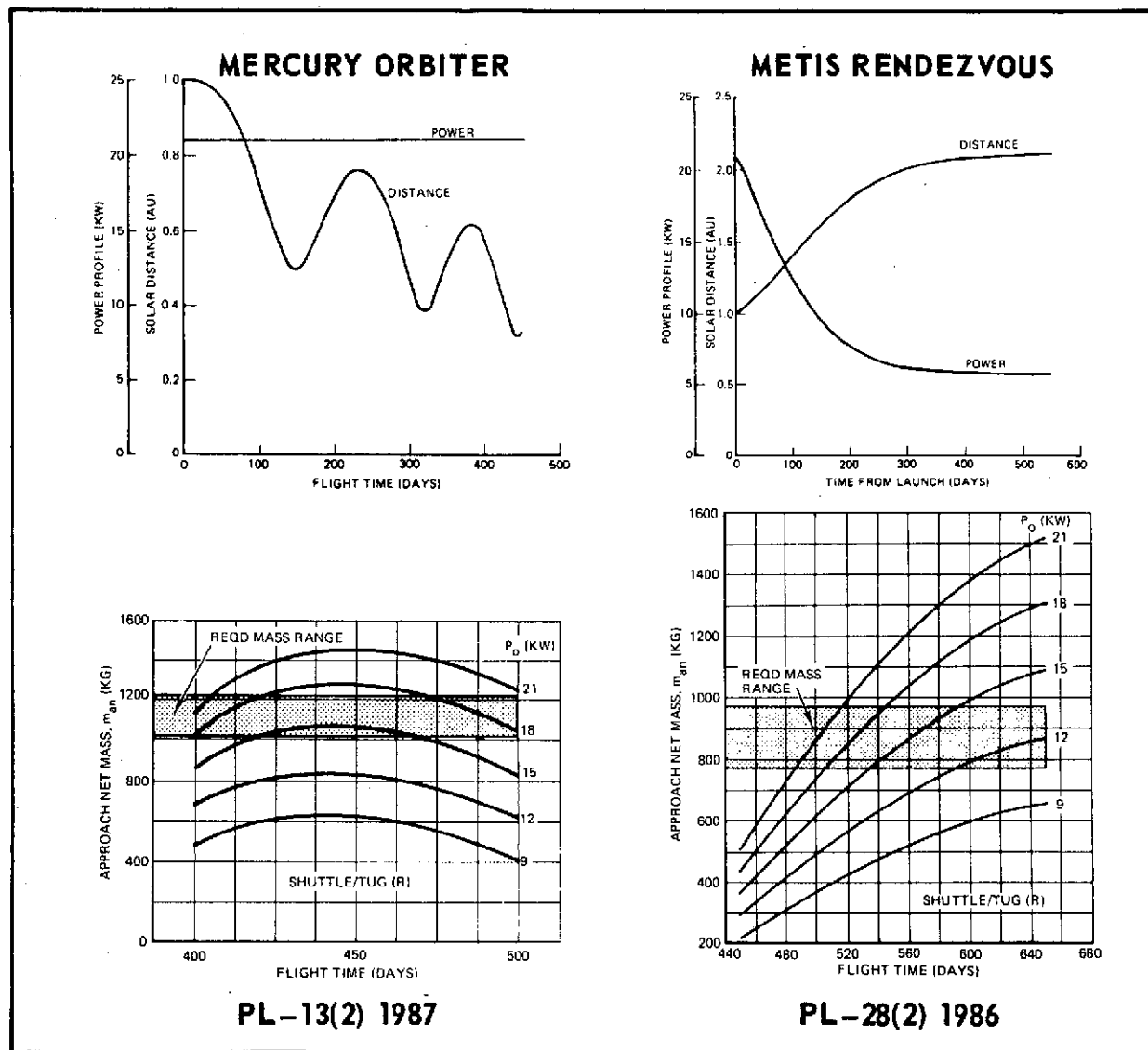


Figure 2-12b. TYPICAL PLANETARY MISSIONS - 1986,1987

SEPS can provide only limited payload support power if developed at the 25 kw of solar power level.

In the case of the Jupiter Orbiter mission, increased power beyond 25 kw would allow SEPS thrusters to operate during the approach to Jupiter, aiding in the capture maneuver, and also allow SEPS to modify the Jovian orbit for close inspection of each Jovian moon. When not thrusting, more power is available for communications so that high resolution imaging can be conducted in shorter periods of time. All of the RI work presented on Figures 2-12 was conducted with very conservative mass-to-power ratios based on processing screen power with the associated losses and weight penalties. The Jupiter missions, which chemically retro SEPS into the capture orbit, will benefit greatly from improved (lower) mass-to-power ratios.

Figure 2-13 shows NSI's analyses of SEPS potential for an exciting new set of "out-of-the-ecliptic" missions that allow examination of the solar magnetosphere and solar surface with high resolution instruments over the

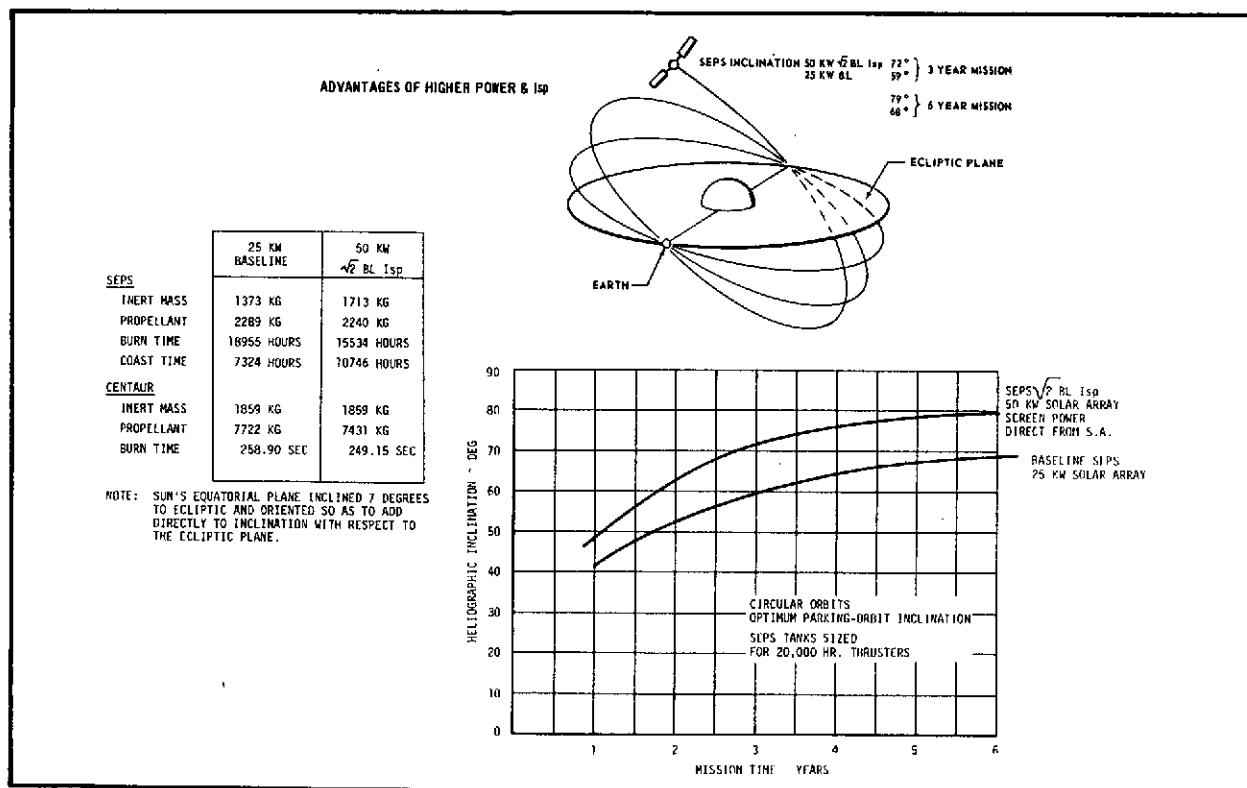


Figure 2-13. "OUT-OF-THE-ECLIPTIC" MISSIONS FOR SEPS

entire solar sphere. In the particular example shown, the SEPS is launched by a Titan Centaur vehicle. The curves demonstrate the effect of three parameters. The curve showing the higher heliographic inclination versus mission time illustrates the advantages of increased power, better power-to-mass ratio by taking thruster screen power directly from the solar arrays, and the value of the option of operating at a factor of 2 greater (2200 Vs/1100 Vs) thruster screen voltage to achieve an Isp of 4243 seconds rather than a baseline 3,000 seconds. The higher achievable inclination for the upper curve is due solely to the higher Isp and lower mass-to-power ratio from direct use of solar array power for screen power.

A design approach similar to that used on the 50 kw system but at 25 kw level would finally achieve the 80-degree inclination but in a much longer trip time.

This discussion has not covered all the implications of Figures 2-9 and 2-10. Thoughtful perusal of these figures will indicate that desirable characteristics for a standard core SEPS to achieve enhanced planetary mission suitability are:

- Improved average thrust-to-mass ratios
- Option to operate at high or low Isp to match requirements of a specific mission
- Reserve power to support larger payloads and higher communications rates at extended distances from the sun.
- Maneuver power to extend scientific mission capabilities after arrival at the target planet.

Improved average thrust-to-mass ratio can be achieved by:

- Increased solar array area and higher kw/kg values for the arrays by fuller exploitation of present technology
- Taking thruster screen power directly from the solar arrays and improving power processor efficiency for the remaining ≈20 percent of the power
- Fuller utilization of the ion thruster's inherent capabilities indicated by the last several years of NASA's technology program.

RELATED TECHNOLOGY ASSESSMENTS

NSI has reviewed the available technology base derived from NASA's thruster technology and research programs, has reviewed industrial developments of devices suitable for solid state power processing, and has reviewed the literature on solar cell technology. The conclusions of this assessment are:

- Thrusters have the inherent ability to operate over screen voltage ranges of about 800 v to more than 2800 v and at beam currents corresponding to .05 amp to 4 amps in a 30 centimeter thruster
- Solar arrays are both feasible and desirable direct sources of thruster beam power
- Higher voltage solar arrays (400 v up to 1100 v) are both feasible and desirable
- The potential exists for lower cost and higher reliability solar arrays than those assumed in prior studies
- Higher voltage power processors than those baselined for prior studies (200 v to 400 v) are feasible
- Exploitation of the technology base will provide a SEPS of significantly greater mission flexibility than the baseline derived from previous studies.

Section III

IMPACT OF SEPS OPERATION WITH STS ON ORBITER, IUS, TUG PHYSICAL INTERFACE REQUIREMENTS

3.1 GENERAL CONSIDERATIONS

The delivery to or retrieval of SEPS from typical IUS/Tug payload transfer orbits imposes no additional physical interface requirements since SEPS as an individual payload to be delivered has very modest support requirements well within the design capabilities proposed for IUS and Tug or those baselined for the Orbiter.

Figure 2-8, the System Operational Profile, showed that only three scheduled SEPS launches and one retrieval were required to accomplish the reference mission model from 1981 through 1991.

SEPS augmentation of IUS-Tug transportation capabilities allows the use of the GPME concepts described earlier, which greatly simplifies the Orbiter, IUS, and Tug ground operations involvement in multiple payload delivery operations. The transport shell always presents a single structural payload interface to the IUS, Tug, and Shuttle Orbiter. Because all payload inertial loads are distributed into the shell which distributes the total load to the Orbiter's cargo bay longerons in an acceptable way, loads on IUS and Tug are lower than design limit loads derived from certain individual payloads carried by IUS and Tug.

The additional interface requirements for STS elements therefore derive from the fact that with SEPS in the system multiple payload cargo manifests may contain up to seven or eight payloads instead of three to four. The primary impact, as might be expected, is in the avionics support areas of telemetry, command, and power supply.

Other potential added demands are in the areas of propellant dumping, venting, and RTG cooling, or other payload environmental factors. None of these represent extra requirements since the character of the multiple payloads with SEPS does not present a greater requirement than some of the more complex single and dual payloads transported without SEPS. Manifolding of multiple payload requirements on the transport stage results in interfaces equivalent to a single payload.

Safety and interface discussions will be considered in the following sequence:

- SEPS as one of a multiple payload group for delivery in terms of Orbiter safety requirements and interfaces
- Multiple payload avionics potential requirements
- Gases and liquids venting and dumping requirement

3.2 SEPS SAFETY AND INTERFACE CONSIDERATIONS IN RELATION TO ORBITER

Figure 3-1 shows SEPS with other schematically represented payloads in a transport shell with Tug in the Orbiter cargo bay. IUS would mount similarly. The transport shells for IUS and Tug are essentially identical and could be developed for interchangeability. SEPS is mounted on a standard GPME diaphragm and has no direct structural interface with the Orbiter or IUS-Tug.

SEPS, if nominally fueled for the initial deployment mission, has a mass of about 2725 kilograms (6,000 pounds). SEPS contains only four fluids: pressurizing N_2 , battery fluids, mercury, and hydrazine.

The pressurizing N_2 for the mercury expulsion system has a peak charged pressure of 58 N/m^2 (40 psia). The N_2 is contained inside the mercury propellant tank; tank design limit load is controlled by the 9 g Shuttle crash load factor. Design for containment to peak cargo bay temperatures is a negligible mass penalty. Pressure relief venting to the cargo bay interior is acceptable. No caution and warning (C&W) signals or control from the orbiter is required.

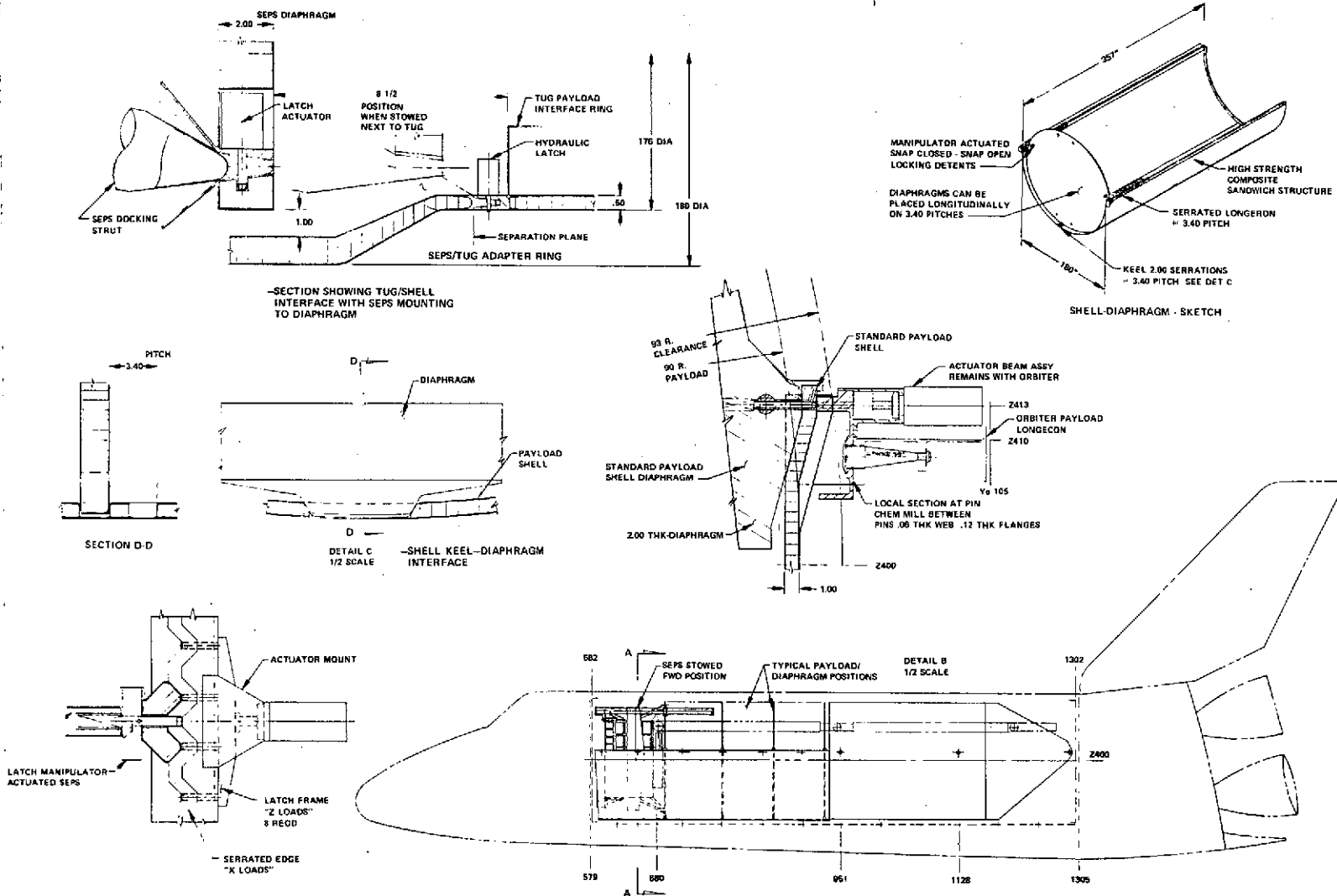


Figure 3-1. SEPS AND INITIAL PAYLOAD GROUP IN THE ORBITER CARGO BAY

The N_2 for ACS has a peak charge pressure of 290 N/cm^2 (200 psia) and is also within the pressure shell of the N_2H_4 tanks. The tanks contain 109 kg (240 pounds) of N_2H_4 . The tanks will be designed for containment of N_2 and N_2H_4 at peak cargo bay temperatures. Backup N_2 pressure relief vent to the cargo bay will be used for added safety. No propellant dump for this quantity of N_2H_4 is required. No C&W or command lines to or from the Orbiter are required.

Because of the space thermal requirement both propellant tanks are insulated. No condition that has not destroyed the Orbiter will cause monopropellant decomposition of the N_2H_4 in SEPS.

SEPS, like most long-life spacecraft, uses Nickel-Cadmium batteries which are sealed. The batteries will be designed for containment. No C&W or command lines to or from the Orbiter are required.

SEPS is designed to have no separation or deployment ordnance. All separation functions are controlled by reversible motors or with the aid of the manipulators. Orbiter may derive status information and command control for latching.

3.3 IUS-TUG AVIONICS SUPPORT TO SEPS

NSI believes the most desirable approach to avionics support for all payloads mounted on Tug is from Tug, since the support must be continued after separation from the Orbiter. During ascent, Orbiter must support Tug by provision of primary power and data links into the Tug.

The following requirements for avionics support of SEPS from Tug exist:

- During prelaunch after transport shell has been mated to Tug and after installation in Orbiter:
 - * 150 watts power and 1,000 kbits/sec digital data during brief flight readiness status check periods. Thermal control power of about 200 watts could be required depending on temperature of Orbiter's N_2 purge gases
- During Orbiter ascent:
 - * Nominally no support; 200 watts periodically if required for thermal control

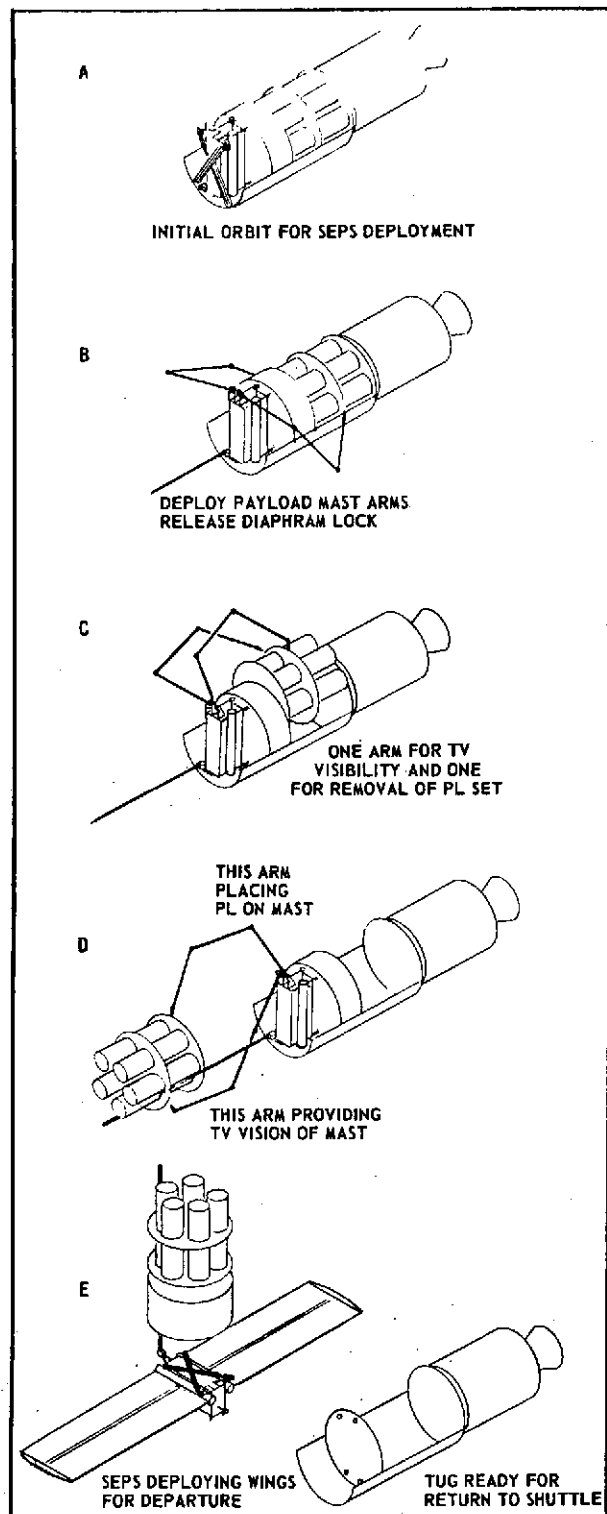


Figure 3-2. PAYLOAD TRANSFER
INITIAL SEPS SORTIE

- During Tug deployment, parking orbits and ascent to SEPS initial parking orbit:
 - * 200 watts primary power for thermal control
- SEPS initial startup and transfer of initial payload to SEPS payload mast:
 - * 600 watts, 10,000 bits/sec digital TV data and telemetry. Uplink data rate 10 kbits/sec. This support requirement would last approximately 1 hour. 1000 watt peak power required. Total energy required 3 kw/hr.

This deployment and initial payload transfer sequence is shown schematically on Figure 3-2. All of the above requirements are within Tug proposed capability. As indicated on Figure 3-2, one of the SEPS phased array antennas is exposed and SEPS' own systems can supply the capability.

3.4 TUG—IUS SUPPORT TO PAYLOADS IN TRANSPORT SHELL

McDonnell Douglas and General Electric, teamed for the MSFC directed "IUS/Tug Payload Requirements Compatibility Study," reported in their midterm review the results of a payload design engineering committee analysis to determine nominal, maximum, and minimum values of Tug payload support requirements.

The peak power and peak data rates are part of the final deployment functional checks and would be conducted on SEPS after SEPS had achieved the payload mission deployment conditions. SEPS, in this case, relieves Tug of ever having to meet the peak power and data rate requirements indicated by the committee analysis.

In further analysis the committee changed their approach to checkout test while still onboard a transport vehicle. Only payload status checks will be conducted until the payload spacecraft are deployed. All spacecraft payload demands indicated are therefore reduced to data rate levels of ≈ 1 kbit/sec and power levels to 200 or less watts. SEPS data rate capabilities are in the megabit range so this poses no problems for SEPS.

Section IV

PROGRAM SUPPORT AND COST ESTIMATES

4.1 PROGRAM SUPPORT

SEPS is relatively simple. It is nearly all electrical. It has compact dimensions for transport and storage. Very modest buildings and checkout equipment will support its few launch preparation and refurbishment activities. The largest cost in SEPS operations is for mission planning and flight control personnel. These personnel must know SEPS configuration, functions, subsystems, and components in detail. The personnel that support the launch preparation functions, the one or two refurbishments, and the sustaining engineers must know the system intimately.

Reference to Figure 2-7, the system operational profile shows that in 11 years there are only eight planetary and three earth orbital launches to accomplish the reference mission model. There is only one SEPS refurbishment for relaunch. There are only 29 earth orbital sorties by SEPS over the 11-year period. Recall the SEPS autonomous cruise and autonomous terminal approach phase of the rendezvous (when desired) capability so that a sortie, typically 90 days or less total time, has only four periods of peak activity where the mission planning and flight control crews are fully utilized. These periods of peak activity are associated with the following functions:

- Detail planning of the next sortie in conjunction with the payload sponsors and developers and Shuttle flight planners.
- Systematic retrieval of the payloads to be returned to earth by Tug and orbiter, and initiation of the cruise phase down to the Tug rendezvous orbit
- Rendezvous with Tug, delivery of down payloads, acceptance of up payloads, and initiation of the ascent cruise phase to deploy up payloads at their mission conditions
- Deployment of payloads at their mission station and performance of servicing functions for any other payloads requiring that function.

Readers interested and experienced in mission planning and flight control recognize those four functions in past space experience as time consuming and

demanding of a large investment in man-hours. For this SEPS group however, the longest involvement of any intense activity is with the payload sponsors in the detail mission planning. Other functions require two to three days' full utilization of a 16-man team around some key flight operation. A small investment in time and people (in spite of past experience) can accomplish in the SEPS program the four functions described on the preceding page, because:

- 13.2 million dollars is allocated for initial onboard software (\$4.5 M) and flight control center (\$8.7 M) software to automate the mission planning and flight control
- The group does only the SEPS specific detail planning. Two other principal groups providing controlling event sequences and system function timelines to which SEPS must perform. The advance planning input comes from the Shuttle/STS Utilization and Master Scheduling Center. The detailed specific mission timeline event sequence for activities influencing Shuttle is established by the Shuttle Operations Center.

In view of the above factors, NSI believes that a small 45-man team, organized as shown on Figure 4-1, can accomplish the complete program support. Volume III of this series, Design Reference Mission Description and Program Support Requirements, discusses the subject in some detail.

SEPS transportation, due to its small packaged size (3m x 3m x 5m) and light unfueled packaged mass (2 tons), is convenient and inexpensive. The total supporting equipment and facilities investment is about \$8.8 million, \$5.3 million of which are allocated to computers and peripheral equipment. Computers are underutilized except for the previously defined periods of peak activity and could be utilized by the SEPS operations center (SEPSOC) host institution for its other functions. If the host center has available computer capacity for SEPS part time utilization, only \$3.5 million is required for the SEPSOC facility and equipment. The required initial software package cost was estimated at about \$8.7 million.

Because of the above factors, NSI believes that SEPSOC facility and equipment cost factors could not control the location of SEPSOC. To accomplish the program cost savings indicated by the 45-man total program support

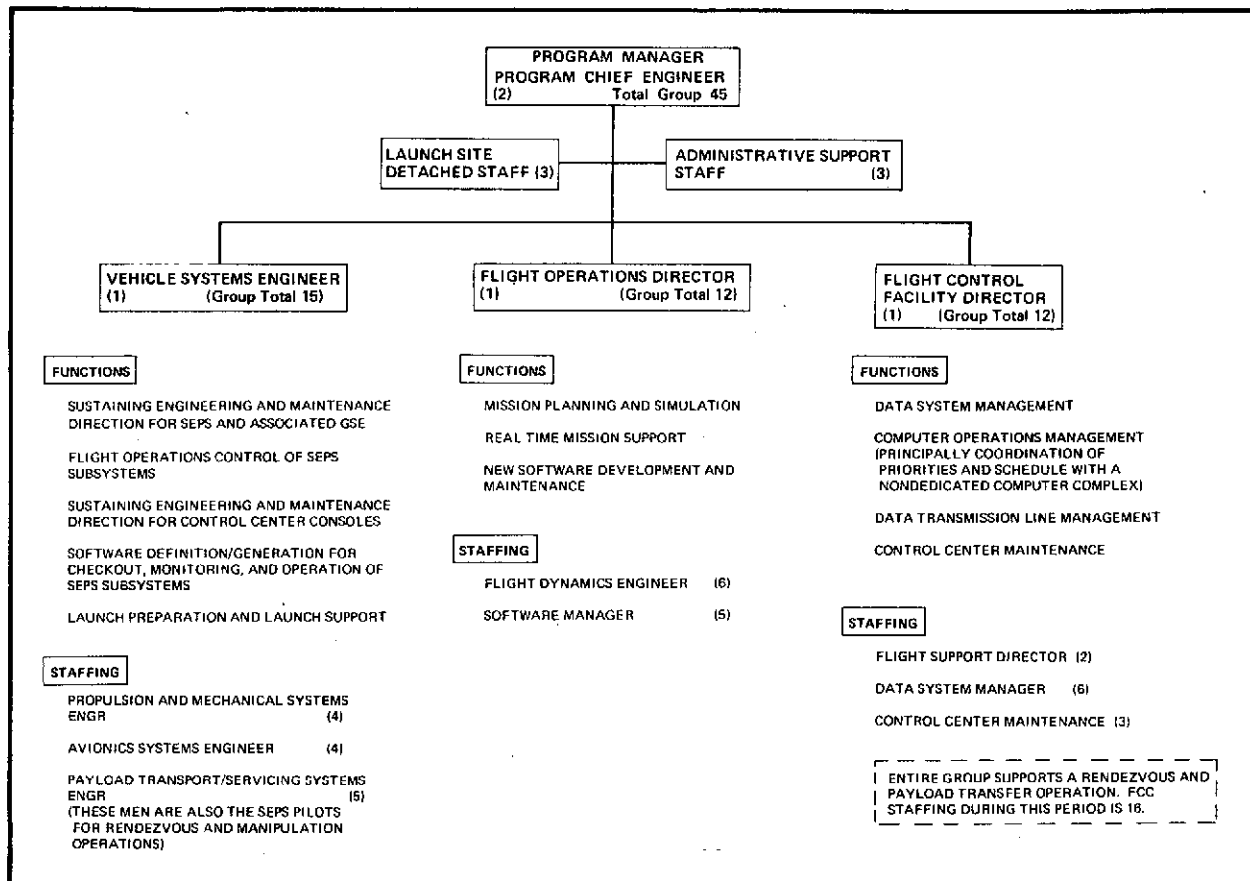


Figure 4-1. SEPS PROGRAM SUPPORT ORGANIZATION

team, the SEPSOC must be located at the center that is given the total program responsibility for SEPS.

4.2 PROGRAM COST SUMMARY

The cost estimation assumptions used in the analysis are as follows:

There will be a single SEPS DDT&E and production program managed by one organization. The basic core vehicle will be capable of accomplishing either the earth orbital functions or the deep space mission when certain components and sensors are added. This will, on occasion, result in SEPS implementing missions which do not require its full capability in solar array power or thrusters. NSI strongly believes it is false economy to have tailored, reduced

capability vehicles just to save a few hardware production dollars on a specific production vehicle. Therefore, the single DDT&E program will phase into production at the most economical rate for the total inventory. Each SEPS, after production, will undergo a rigorous flight readiness check as a part of the final acceptance testing. Then it will be stored in a hermetically sealed, inert gas filled container with its status check and power supply hardlines used in ascent flight carried through the container walls to a test umbilical. As each SEPS is completed, accepted, and installed in its storage container it goes to the launch site for immediate launch or to the SEPSOC for inventory storage.

When production of inventory and refurbishment spares are complete, the DDT&E/production contract is terminated. There is no sustaining engineering support team at any contractor or subsystem supplier's plant included in these cost estimates after production is complete. This does not preclude NASA from electing to have SEPSOC operated by a contractor and the DDT&E contractor may be the successful bidder for the SEPSOC support.

It is management wise and technically feasible that the 45-man program support team at the SEPSOC make any modifications or system changes found later in the program to be absolutely necessary.

Other assumptions are:

- Production is continuous for 11 vehicles. The first vehicle is delivered 30 months after authority to proceed (ATP).
- All \$ are 1974 \$.
- There are four planetary missions, each flown with a backup spacecraft requiring a total of eight planetary SEPS. Only two EO SEPS are required. One production spare is planned and the integrated system test article is refurbished at the end of production to provide a second spare.
- One refurbishment is included in the cost estimates which would extend the SEPS capability beyond the 1991 operational time groundrules for this cost effectiveness study.
- No costs are included for mission special planetary spacecraft sensors.
- The center given responsibility for the science package and mission operation will assume flight control of SEPS and the science package

at some time after cruise mode is established for the initial planetary trajectory. Only periodic advice or consultation from SEPS vehicle systems specialists will be provided on request of the planetary control groups after cruise mode is established.

Table 4-1 presents the SEPS total program costs including planetary vehicle core development costs and the launch support operation for eight planetary vehicles.

Table 4-1. SEPS TOTAL PROGRAM COST SUMMARY

STAGE DDT&E	97.5
EO Functions (Transport Mast & Manipulators)	(8.3)
Basic Stage	(89.2)
STS GPME DDT&E	2.5
PL Shell & Diaphragms	
FLIGHT ARTICLE PRODUCTION	145.9
8 Planetary Vehicles	(97.6)
3 EO Stages	(39.6)
STS GPME	(1.5)
Stage Refurbishment and Maintenance	(7.2)
SEPS OPERATIONS CENTER INITIAL COSTS	17.9
Facility and Equipment	(8.8)
Initial Software Package	(8.7)
Initial SEPSOC Spares	(0.4)
SEPS SYSTEMS OPERATIONS	26.2
Personnel (45 men 11 years)	(23.7)
Computer Support	(2.1)
Flight Article Consumables	(0.4)
TOTAL PROGRAM COSTS	290.0

Table 4-2 is the DDT&E cost broken down by major subsystem and functional area of the program.

Figure 4-2 shows the prime contractor's total manloading versus time for DDT&E and production for the first 36 months of the contract. Beginning at 30 months into the contract, SEPS are delivered at the rate of three per year until delivery of the 12th SEPS (the refurbished test article). Total DDT&E plus production duration is approximately 6 years.

Table 4-2. DDT&E COST BREAKDOWN

	TOTAL DDT&E	CORE VEHICLE	PLANETARY PECULIAR	EO PECULIAR
STRUCTURES & THERMAL CONTROL	\$ 4.8	\$ 4.8		
PROPULSION	9.1	9.1		
POWER DISTRIBUTION	1.0	1.0		
SOLAR ARRAY	7.8	7.8		
DATA MANAGEMENT	3.4	3.4		
COMMUNICATION	2.2	1.4	\$ 0.5	\$ 0.3
NAVIGATION & GUIDANCE/ATTITUDE CONTROL	9.2	6.0	2.2	1.0
INTEGRATION & TEST CHECKOUT	6.7	6.7		
TEST HARDWARE	21.3	19.8	1.1	0.4
STAGE GSE	5.0	4.0	0.2	0.8
SOFTWARE	4.5	4.5		
LOGISTICS	0.5	0.1		0.4
S.E.&I.	6.8	6.8		
PROGRAM MANAGEMENT	6.9	6.9		
BASIC SEPS	89.2	82.3	4.0	2.9
Δ FOR EARTH ORBITAL FUNCTIONS OR (PAYLOAD MAST & MANIPULATOR)	8.3			8.3
TOTAL	97.5			

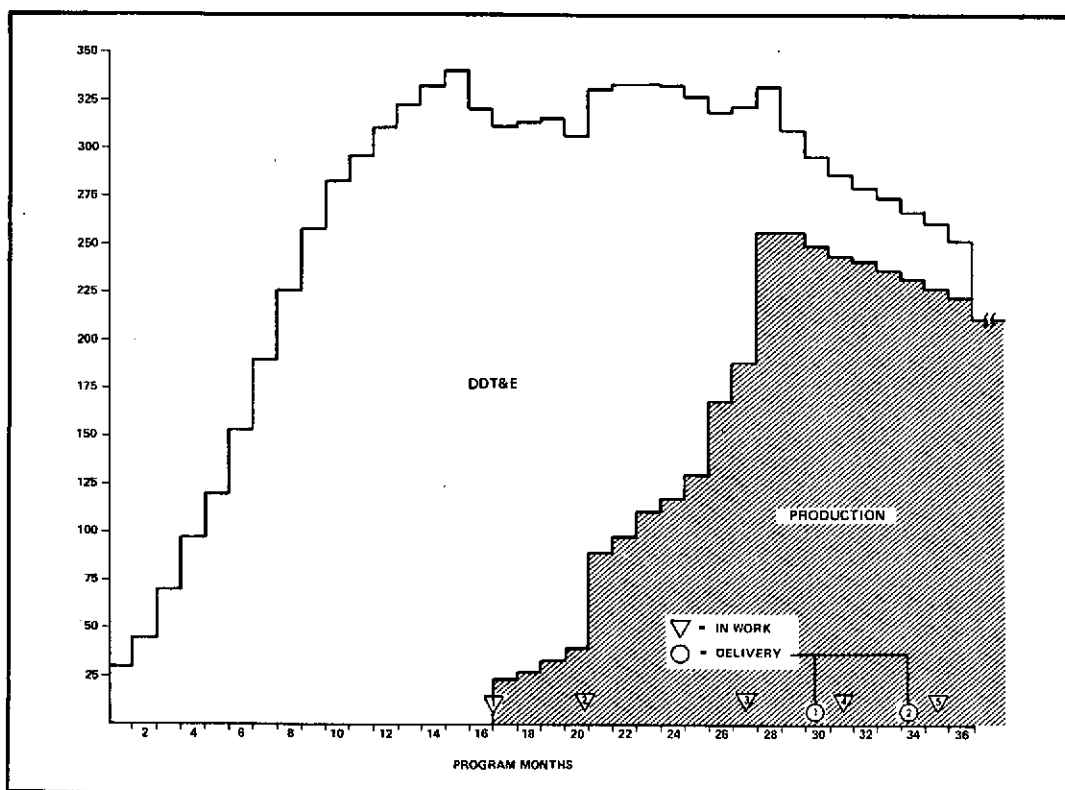


Figure 4-2. TOTAL SEPS PROGRAM MANLOAD MONTHS 1 THROUGH 36 ONLY

Section V

RECOMMENDATIONS FOR ADDITIONAL EFFORT TO DEFINE THE SEPS UTILITY AND CONFIGURATION

Subsection 2.3 delineated a series of configuration decision controlling factors and highlighted the fact that the selection criteria, within the next five years at least, are not subject to technical/programmatic "optimization" but are dependent upon a NASA policy decision. the configuration for selection choices are to configure for:

- A. The minimum to meet absolute needs for some reference mission model specified by NASA
- B. Cost effectiveness against a reference mission model considering only transportation cost savings
- C. Configure for cost effectiveness considering all functions SEPS can provide plus addition of those low/moderate cost features that greatly enhance functional capability and mission flexibility.

Until NASA policy selects one of these choices, further configuration design studies and system definition studies are largely technology exercises.

NSI believes choice C is the appropriate one considering the fact that mission models and payload configuration concepts are not only changing as the value of new missions and concepts are recognized, but are also being changed by payload sponsors and mission planners in response to STS evolving characteristics. This latter change influence is undesirable since the payload planners should be specifying desirable STS characteristics rather than compromising payload capabilities and objectives to meet STS limitations that are removable at modest cost by implementation of the EO SEPS program.

To implement choice C the following additional effort is recommended.

- Assess what desirable payload objectives are possible with increased net payload mass, and surplus power to support higher data rates and higher resolution sensors. Assessment of the value of space mobility for science packages enabling total surface mapping, mapping of magnetospheres, close inspection of planetary satellites, etc.

- For earth orbital missions, similarly assess the value of improved capability in meeting present payload objectives and the value of achieving new objectives with the increased allowable payload mass provided by SEPS.
- For payloads that are reasonably well defined, assess the value in terms of cost for the deployment assistance, servicing, maintenance, and retrieval abilities of a manipulator equipped SEPS configuration similar to, or improved from, the concept evolved in this study.
- Provide a value assessment for cost savings resulting from a higher power SEPS ability to execute missions in a shorter time, respond quickly to needs for servicing, etc.
- Establish low development and low production cost design approaches for the solar arrays, power processors, and thrusters.
- Investigate further the potential major cost reductions possible through commonality of Tug and SEPS avionics systems.